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The Boundaries of the Firm: A Problem Solving Perspective

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Declaration of Authenticity and Author's Rights

Signed:
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To Huilan

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Although the current author takes full responsibility of the work presented in this thesis, there are some people whom the author would like to express special gratitude towards.

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Abstract

The Boundaries of the Firm: A Problem Solving Perspective

This thesis contributes to the problem-solving perspective (PSP) of the boundaries of the firm, both theoretically and empirically.

Two main theoretical contributions are made.

First, although it is generally acknowledged that the NK modelling literature is a source of theoretical inspiration for PSP, this literature is probably less familiar to most economists working on the theory of the firm. To fill the gap, the NK modelling literature is systematically reviewed and is linked more closely to the problem solving perspective.

Second, on the basis of a detailed review of the PSP literature, it is argued that knowledge-set interaction and decomposability are two analytically distinguishable dimensions of complexity and should be treated as separate variables in empirical analysis.

With reference to other closely-related literatures, such as the knowledge-based view, organizational learning, and innovation, it is argued that a firm's existing knowledge base has a significant impact on the organization of its problem solving activities. However, this dimension has been missing or ignored in the current PSP literature.

It is also noted that the PSP has mainly been applied to the organization of R&D activities (i.e. technological problem solving). It is concluded that once joined with Porter's activity analysis (in particular, the value chain analysis), the PSP could be applied to other non-R&D activities and be further developed into a more general framework for discussing economic organization and the boundaries of the firm. Some ways of doing this are outlined

On the empirical front, a regression-based analysis of the Chinese consumer electronics industry is carried out. A small primary dataset of firms (142 cases) in this industry was assembled by employing interviewing and questionnaire techniques. Based on a review of previous empirical studies, key hypotheses were tested.

More specifically, binomial and multinomial regression models were estimated. Hypotheses from PSP and the now dominant transaction cost theory were tested,

with one aim being to establish the relative importance in terms of explanatory power. The empirical results are more supportive of the problem-solving perspective rather than the transaction cost theory.

Four categories of explanatory variables were included in the regression models:

(1) Variables measuring "problem complexity" (problem structure, knowledge set interaction and decomposability);

(2) Variables measuring a firm's existing "knowledge base";

(3) Variables related to "knowledge characteristics" (such as tacitness and social distribution/embeddedness of knowledge); and

(4) Transaction variables (such as asset specificity, demand uncertainty and appropriability).

The results suggest that PSP variables are important determinants of a firm's organizational choice and their effects are largely in line with theoretical expectations. It is found that the higher the complexity (be it measured by problem-structure, knowledge set interaction, or decomposability), the more likely the problem-solving will be organized in-house rather than through market transactions. Moreover, it is also found that the effects of problem knowledge-set interaction and decomposability are significant for other organizational choices. On the other hand, the effects of problem structure are far less evident, and likely only play a role in the choice between make-or-buy.

The results also lend support to some of the transaction costs expectations (in particular, those related to asset specificity and appropriability). However, in terms of their relative explanatory power (magnitude of effects or the level of significance), the few PSP and knowledge base variables are far better predictors of a firm's organizational choices than transactions cost variables. In other words, the results lend more support to the problem-solving perspective and the knowledge-based view, rather than the transaction cost economics.

The results also suggest that a firm's existing knowledge base is the single most important variable in explaining a firm's organizational choice of technological problem solving. In the existing PSP literature, however, the role of a firm's existing knowledge base has largely been ignored.

The results further indicate that the effects of knowledge-set interaction and decomposability are not always working in the same direction. This lends support to the argument that complexity (knowledge-set interaction) and decomposability should be treated as two distinct variables.

Finally, contrary to the general prediction of the problem solving perspective, the results reveal that as far as the choice between in-house and alliance is concerned, a higher level of complexity tends to favour the choice of alliance rather than in-house—i.e. alliance is preferable to in-house for solving highly complex problem. This suggests, as far as the costs and competencies of governing different types of problem-solving are concerned, alliances are probably not "hybrid" modes of organization. Rather, they are distinct categories of organizational mode in their own rights.

Apart from these main contributions, two detailed critical reviews of the background transaction cost economics literature are presented. One reviews the evolution of the concept of transaction costs in transaction cost literature, aiming to highlight the basic logic of the transaction cost economics, the diversity of the literature and to demonstrate how the concept is applied to the boundary determination of the firm. The second reviews Oliver Williamson's theory of the firm, aiming to illustrate the basics of his method, to highlight his major contributions and to identify the strengths and weaknesses of his theory.

Given that the transaction cost economics is now the dominant approach in the field (in particular, Williamson's approach), and that in many aspects, the problem-solving perspective follows the method of "discrete structural analysis" developed by Williamson, these two reviews are highly relevant to our analysis.

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Chapter 1: Introduction

This chapter consist of two sections. In section 1, we describe briefly the motivations of the thesis. In section 2, we outline the structure of the thesis, highlighting the topics that will be discussed in each chapter.

1.1 Motivations

This thesis is intended to contribute to the ***problem-solving perspective*** (PSP)—an emerging approach to the boundary determination of the firm.

The emerging problem-finding and problem solving perspective (Dosi, Hobday, & Marengo, 2003; Heiman, Nickerson, & Zenger, 2009; Hsieh, Nickerson, & Zenger, 2007; Macher, 2006; Macher & Boerner, 2012; Luigi Marengo, Giovanni Dosi, Paolo Legrenzi, & Corrado Pasquali, 2000; Nickerson, Silverman, & Zenger, 2007; Nickerson & Zenger, 2004) to the boundary determination of the firm seeks explicitly to combine transaction cost economics (Williamson, 1975, 1985b, 1996b), complexity theory (Simon, 1962; Kauffman, 1995) and the knowledge-based view of the firm (Conner, 1991; Conner & Prahalad, 1996; Demsetz, 1988; N. J. Foss, 1996a, 1996b; Kogut & Zander, 1992, 1993, 1996) in explaining how the choice of alternative organizational forms influences the efficient creation of valuable knowledge.

Unlike transaction cost economics, in which the firm is described as an "avoider" (Conner, 1991: p. 139) of the transaction costs associated with opportunism (Alchian & Demsetz, 1972; Williamson, 1985b), in the problem-solving perspective, the firm is described as a routine-based, history-dependent and knowledge bearing problem-solving social entity that adapts experimentally and incrementally to past experiences (Dosi, Hobday, & Marengo, 2003; Macher & Boerner, 2012; March & Simon, 1958; Penrose, 1955). Distinctive in this approach, is an exploration logic that is particularly suited to the problem of value creation and opportunity discovery (Heiman et al., 2009).

Specifically, by exploring an economizing logic of managerial choice to maximize expected values of problem finding and problem solving, the approach tries to work out a discriminating alignment between the problem-solving (knowledge creating) activities, which vary according to their complexity, and the few generic governance structures, which vary according to their costs and competencies to support knowledge development and transfer. Ultimately, the research questions in this perspective reduce to (Nickerson, Yen, & Mahoney, 2012) (1) how can a firm identify valuable problems and opportunities, the resolution of which enables the firm to create and capture value; (2) how can a firm effectively organize—based on the attributes of the problem—the solution search of a chosen problem; and (3) once the solution of a chosen problem is found, how can a firm efficiently implement the solution to create and capture value?

In many aspects, the problem-finding and problem-solving perspective follows the method of “discrete structural analysis” developed by Williamson (1991). Although it adopts a different unit of analysis from TCE, the problem solving perspective applies similarly the logic of “discriminating alignment” (Williamson, 1991) in evaluating the relative costs and competencies of alternative governance mechanisms in solving problems with different attributes.

Specifically, in this perspective, the “problem” is taken as the basic unit of analysis, and the profitable discovery of a high-value solution to a problem (i.e., formation of new knowledge) is the central rationale for choosing the organizational form. Following previous work, it is assumed that new knowledge is generated by combining existing knowledge, and a solution to a complex problem represents a unique combination (synthesis) of existing knowledge. For any given problem, the set of all possible combinations of relevant existing knowledge (i.e., solutions) is represented as a solution landscape the topography of which defines the value of each solution, and the solving of the problem is viewed as a process of searching over the solution landscape for high value solutions (Nickerson & Zenger, 2004).

Based on Simon’s work on problem solving (1962, 1973), Kauffman’s (1993) work on NK modelling, and Kogut and Zander’s contributions to the knowledge-based view of the firm (1988; 1992, 1993, 1995), it is suggested that a few problem attributes (problem complexity, decomposability, and problem structure) and knowledge characteristics (e.g., knowledge tacitness and social distribution) are crucial in understanding the impediments to problem-solving activities (knowledge-transfer and knowledge-formation hazards) (Brusoni, Marengo, Prencipe, & Valente, 2007; Heiman & Nickerson, 2002, 2004; Macher, 2006; Nickerson & Zenger, 2004), different search methods (heuristic or local trial-and-error). On this basis, it is contended that different search methods (heuristic or local trial-and-error) and different problem types could be matched in a way that realizes superior search performance (Gavetti, 2005; Gavetti & Levinthal, 2000; Sommer & Loch, 2004; Winter, Cattani, & Dorsch, 2007). Furthermore, it is also identified that as far as the costs and competencies for implementing solution searches for different types of problem are concerned (by mitigating knowledge formation hazards and other impediments), the few generic organizational modes differ with respect to the dimensions of incentive intensity, communication channels, and dispute resolution regime (Heiman & Nickerson, 2002, 2004; Leiblein, Macher, & Ziedonis, 2009; Nickerson & Zenger, 2004). Finally, the problem-solving perspective works out the discriminating alignment between these problem/knowledge attributes and the few generic organization modes—markets, hierarchies, and alliances—in a cost economizing manner that enables efficient solution search and maximizes expected values of problem solving (Heiman & Nickerson, 2002; Leiblein & Macher, 2009; Macher, 2006; Nickerson & Zenger, 2004).

In short, the problem solving perspective has contributed valuable new insights to the firms' organizational choice of productive activities (in particular, technological problem solving activities), and it has shown great potential for being developed into a more general framework for understanding economic organization and the firm boundary.

Despite these accomplishments, many issues remain unresolved in this approach. In the first place, as an emerging perspective, there is currently little empirical evidence to support the PSP hypotheses; therefore, more empirical studies are warranted. In addition, in the existing literature, the problem-solving perspective has mainly been developed as a theory regarding the organization of *technological* problem solving (or R & D). In this story, new knowledge is generated by combining existing knowledge, and a high-value solution to a complex problem represents a novel combination (synthesis) of existing knowledge. However, knowledge is but one of the many resources that are needed for a firm's value creating activities, and R&D is only one of the many functional activities in a firm's value chain. One might wonder, apart from technological problem-solving, to what extent, the problem-solving perspective could be applied to the organization of other non-R&D activities and be further developed into a more general framework of understanding economic organization.

Moreover, in the existing literature, the problem solving perspective has mainly been applied to the choice of make-or-buy, or the choice between equity-based and contract-based alliance. When the choices are extended to a full range of organizational modes, it is not totally clear how the problem solving variables might affect organizational choices. For example, given that a firm does not have all the knowledge that is required to solve a complex problem, in the face of the choice between in-house and alliance, will a higher level of problem complexity favour the choice of in-house, or the choice of alliance?

Relatedly, and somewhat ironically, even though the problem-solving approach is explicitly developed as "a knowledge-based theory of the firm" (Nickerson & Zenger, 2004), the role of a firm's existing knowledge base in shaping its organizational choice has not been sufficiently discussed (Nickerson et al., 2012). Accordingly, it is not entirely clear whether and how a firm's existing knowledge base would affect its organizational choice of problem-solving activities. Is the effect independent of other variables, or it is working in conjunction with other variables?

Up to now these are basically open questions, and in this thesis, we would explore some of these questions.

In short, we intend to contribute to the problem solving perspective on two fronts. On the theoretical front, we provide a detailed review of the existing problem solving perspective literature, with the aim to present its basic insights, to demonstrate its substantial potential, to identify the gaps in the existing research and to sketch out some directions for further developing this emerging perspective.

On the empirical front, using project-level survey data collected from Chinese consumer electronics industry, we empirically test some problem solving perspective hypotheses alongside other competing hypotheses to examine the relative explanatory power of the problem solving perspective. On the basis of an extended review of the empirical evidence relevant to the problem solving perspective variables, we compare our results with those of the existing studies, and then draw our conclusions.

1.2 Thesis Outline

Given that the transaction cost approach is still the dominant approach to the theory of the firm (in particular, the *determination of the firm's boundaries*), we start our thesis with two reviews of the transaction cost economics literature.

Chapter 2 is devoted to a review of the evolution of the concept of transaction costs in the transaction cost economics literature.

This chapter consists of two parts. In part one, we review the evolution of the concept of transaction costs in early transaction cost literature (to the end of 1970s). By identifying a few critical steps in the early evolution of the concept, we demonstrate how some consensus regarding the connotations and natures of "transaction costs" emerges over time. Specifically, these few critical steps are marked by the publication of a series of papers—i.e., Coase (1937), Coase (1960), Arrow (1969), Cheung (1968, 1969a, 1969b, 1970) and Dahlman (1979), each of which contributes in some aspect to a deeper and clearer understanding of transaction costs. Fueled in part by these contributions, at least by the end of 1970s, a certain consensus on the connotations and natures of "transaction costs" emerges, viewing transaction costs (1) as the costs of running institutions, which universally exist in any mode of resource allocation; (2) through the lens of contract, around different phases of which transaction costs evolve; (3) with a connection to property rights, and; (4) as resulting from "lack of information".

In part two, we go on to show that once the consensus emerges, the expanding branching of distinct approaches within transaction cost economics further advances our understanding of transaction costs in some particular aspects. Specifically, we review on a selective basis some of the most representative literature in four different approaches within transaction costs economics—i.e., the property rights approach, the agency approach, the measurement approach and Oliver Williamson's governance approach. With particular emphases on their respective contributions to the understanding of "transaction costs" and the corresponding boundary implications, we show that each of the approaches has quite different emphases when applying the transaction cost reasoning to explain the existence, boundary determination or internal organization of the firm.

Chapter 3 is devoted to a review of Williamson's transaction cost economics (Williamson, 1975, 1985b, 1996b; Williamson & Masten, 1995), and in particular, his theory of the firm, which is now the dominant theory in this field.

The chapter consists of three parts. In part one, we summarize the basic elements (or what Williamson calls "precepts") of his approach. Specifically, these basic elements of his "pragmatic methodology" (Williamson, 2010b) include: (1) To take transaction as the basic unit of analysis and to adopt the lens of contract; (2) To pose the problem of economic organization as a micro-analytic problem of *comparative contracting* (Williamson, 2002b, 2003b), and to implement the transaction cost economizing logic; (3) The comparative contractual approach to the issue of economic organization in general and to the theory of the firm in particular, is implemented through a series of key operationalizing moves (Williamson, 1979, 1985, 1991)—i.e., to identify the behavioural assumptions; to dimesionalize the few critical attributes that are responsible for differential transaction costs under alternative modes of governance; to name and explain the few critical attributes with respect to which governance structures differ and then to describe them as discrete structural alternatives; and to work out the logic of efficient alignment; (4) In the contractual world of transaction cost economics, bounded rationality and opportunism have been identified as the two crucial behavioural assumptions for setting up the analysis (Williamson, 1975, 1985b); (5) Asset specificity, uncertainty, and frequency have been identified as the few critical dimensions by which the magnitude of the contractual hazards vary systematically. In Williamson's view, the most critical dimension is that of asset specificity since the governance ramifications of the other two dimensions can not be fully and independently appreciated until joined with asset specificity (Williamson, 1979: p. 239); (6) Transaction cost economics holds that the few generic modes of governance—market, hybrid, hierarchy etc.—differ from each other by a syndrome of internally consistent attributes to which different adaptive strengths and weaknesses accrue. These attributes, as identified by Williamson (1991), are incentive intensity, administrative controls, and contract law regime; (7) Transaction cost economics places a strong emphasis on deriving refutable implications and submitting them to data. It owes much of its predictive content to the "discriminating alignment hypothesis" (Williamson, 1991) which holds that transactions, which differ in their attributes, are aligned with governance structures, which differ in their costs and competencies to implement autonomous and coordinated adaptations, in a discriminating (mainly transaction cost economizing) way; (8) Transaction cost economics is much concerned with public policy ramifications, and it introduces the "remediableness criterion" as the efficiency criterion for public-policy analysis.

In part two, we discuss in detail the basic framework of Williamson's theory of the firm's boundary. In particular, we focus on three critical aspects of the theory, namely, the dimensionalization of transactions, the dimensionalization of governance structures, and the discriminating alignment.

As observed by Williamson (2000, 2010b), transaction cost economics has undergone a natural progression from informal, pre-formal, to semiformal, and finally to full formalization. Full formalism of transaction cost economics began in 1980s and is still in progress. In particular, the paper by Grossman and Hart (1986), and the follow-on paper by Hart and Moore (1990) (known as the GHM model)—which started the (new) "property rights theory" literature (N. J. Foss, 2010b; J.T. Mahoney, 2005)—have been widely viewed as path-breaking works in this regard.

In part three, we review and illustrate some of the basic insights of the GHM model. We show that although the GHM model shares with Williamson's TCE an appreciation for contractual incompleteness and an emphasis on relation-specific investment, there are fundamental differences between these two approaches. Given these differences, the GHM model is at best a partial formalization of Williamson's theory; and indeed, the two theories are better understood as two distinct theories.

Chapter 4 is the core theoretical part of this thesis.

In this chapter, we review the existing problem solving literature, with the aim to present its basic insights, to demonstrate its substantial potential, to identify the gaps in the existing research and to sketch out some directions for further developing this emerging perspective.

The main text of the chapter consists of five parts. In part one, we introduce the general background of the problem-solving perspective, highlighting its synthetic nature (trying to combine transaction costs economics, theory of complex systems, and the knowledge-based view of the firm) and its exploration orientation. In part two, we argue that previous approaches to strategic management and economics organization are primarily concerned with value capture and value protection, while the vital role of value creation has largely been neglected. By contrast, the problem-solving perspective is characterized by a distinctive exploration orientation, and it can potentially offer a superior framework for addressing the issues of value creation and the organization of discovery. In part three, we offer a systematic review of the NK modelling literature (Kauffman, 1993) and link it more closely with the problem-solving perspective. Although it is generally acknowledged that the NK modelling literature (Kauffman, 1993) is a source of theoretical inspiration for the problem solving perspective (Nickerson & Zenger, 2004), this literature is probably less familiar to most economists working with the theory of the firm. What are the basic insights of this literature? How could these insights be linked to the problem solving perspective? These topics are less reviewed systematically in the problem solving perspective literature. We fill this gap by introducing the basic elements and methods of the NK simulation, highlighting its advantages and shortcomings, and presenting the basic insights of recent economic and strategy applications of the NK models.

In part four, we review the core theory of the problem-solving perspective (Brusoni et al., 2007; Dosi, Hobday, & Marengo, 2003; Heiman & Hurmelinna-Laukkanen, 2010; Heiman & Nickerson, 2002, 2004; Heiman et al., 2009; Hsieh et al., 2007; Leiblein & Macher, 2009; Macher, 2006; Macher & Boerner, 2012; Luigi Marengo et al., 2000; Nickerson et al., 2007; Nickerson et al., 2012; Nickerson & Zenger, 2004), discussing in detail a few critical aspects of its underlying logic. These critical aspects are: (1) to identify the few critical dimensions (problem types and knowledge characteristics) by which the magnitude and types of coordination and incentive challenges to problem solving vary systematically; (2) to demonstrate how different search methods (heuristic search or local trial-and-error search) and different problem types could be matched in a way that realizes superior search performance; (3) to show that the few generic organizational forms (market, alliance, authority-based hierarchy and consensus-based hierarchy etc.) differ in terms of their costs and competencies in implementing different search methods, and finally (4) to work out the discriminating alignment between the few problem/knowledge attributes and the few generic organization modes in an economizing manner that enables efficient solution search and maximizes expected values of problem solving.

In part five, we identify some non-trivial gaps in the problem solving perspective literature. We then sketch out some specific ways for filling the gaps and for further developing the problem solving perspective.

Specifically, on the basis of an extensive review of the whole PSP literature, (1) we argue that knowledge-set interaction and decomposability are two analytically distinguishable dimensions; accordingly, they should be treated as two separate variables; (2) with reference to some other closely related literature such as the knowledge-based view, organizational learning, and innovation literature etc, we contend that a firm's existing knowledge has profound impacts on the organization and performance of its problem solving activities; however, this dimension has been missing or at least has been seriously ignored in the existing problem solving perspective literature; (3) we note that the problem solving perspective has mainly been applied to the choices of make-or-buy, but less to other organizational choices (e.g., choice among various alliance forms, or the choice between in-house and alliance), and we doubt—as far as the governance of problem-solving is concerned—whether these alliance forms are really "hybrid" modes of organization lying somewhere between the polar modes of arm's length market contract and hierarchy along a hypothetical continuum; (4) we note that the problem solving perspective has mainly been applied to the organization of R&D activities (technological problem solving), we contend that once joined with Porter's activity analysis (in particular, the value chain analysis), the PSP framework could be applied to other non-R&D activities and be further developed into a more general framework for discussing economic organization and the boundaries of the firm. We propose some specific ways of doing this.

Chapter 5 is dedicated to a review of the existing empirical evidence relevant to this research.

Admittedly, as an emerging perspective, very few empirical studies are expressly designed to examine the problem-solving perspective. This does not mean, however, that relevant empirical evidence exists only in the empirical problem-solving perspective literature. In fact, in some other streams of literature which are closely related to the problem solving perspective (in particular, the knowledge-based view literature and the transaction cost economics literature), many of the relevant variables have been explored in some way. Whenever relevant, our review will extend to these background literatures. For each variable, the evidence regarding the its organizational implications for the make-or-buy decision and for alliance governance will be discussed separately.

For the convenience of the discussion, relevant variables are grouped into three categories: (1) those related to problem complexity—i.e., problem structure, complexity, and decomposability; (2) those related to a firm's existing knowledge base—i.e., absolute and relative knowledge base, breadth and depth of knowledge base; and (3) those related to knowledge characteristics—i.e., tacitness and social distribution/embeddedness of knowledge. Accordingly, the main text of this chapter is organized into three parts, each covering empirical evidence relevant to one category of variables.

Chapter 6 is devoted to the econometric analysis of the data, the test of hypotheses, and the discussion of our empirical findings.

Using data collected from the Chinese consumer electronics industry, we empirically examine the underlying determinants of the firms' organizational choice for their R&D activities, which, in the first place, is deemed as a problem solving process given their existing knowledge base. Special attention is therefore devoted to those variables associated with the problem-solving perspective.

In this chapter, we start by outlining the method and process of our data collection, as well as the industrial background of our empirical setting. We then explain how the dependent and independent (explanatory) variables in our analyses are defined and measured. Econometric analyses using binomial and multinomial regression techniques comprise the main part of this chapter. In the binomial estimations, the organizational choices are treated as a series of binary choices and the probit regression technique is used to identify the determinants of these choices. Specifically, the section begins with a brief discussion of some of the technical details of the binary probit model. The estimation results of a series of binary probit models are then presented and the underlying determinants in each circumstance are identified separately. In the multinomial analyses, we start by introducing at some length the technical details of the multinomial logit model. On the basis of these technical discussions and using the first-stage results as a benchmark, we present the results of the multinomial logit estimations.

Chapter 7 is the concluding chapter of this thesis, and consists of three parts. In part one, we compare our results with those of the previous relevant studies and make some comments. In part two, we discuss the limitations of this research. In part three, we make some concluding remarks, summarizing the key findings and contributions of this thesis.

Chapter 2: The Evolution of the Concept of Transaction Costs: From Ronald Coase to Oliver Williamson

The chapter consists of two parts. In part one, we review the evolution of the concept of transaction costs in the early transaction cost literature (to the end of 1970s). Specifically, by identifying the few critical papers that have made substantial contributions to the understanding of "transaction costs", we demonstrate how some consensus regarding the connotations and natures of "transaction costs" emerges over time. In part two, we go to show that once the consensus emerges, how the expanding branching of distinct approaches within transaction cost economics further advances our understanding of transaction costs in some particular aspect. The chapter ends with a conclusion section summarizing our main points.

2.1 The Evolution of the Concept of Transaction Costs in the Early Transaction Cost Economics Literature

Below, we identify a few critical steps in the evolution of the concept of "transaction costs" in the early transaction cost literature (to the end of 1970s). These few steps are marked by the publication of a series of papers from 1930s to 1970s. Specifically, these papers are: Coase (1937), Coase (1960), Arrow (1969), Cheung (1968, 1969a, 1969b, 1970) and Dahlman (1979). At least by the end of 1970s, a certain consensus on the connotations and nature of "transaction costs" emerges.

2.1.1 Coase (1937)

In his 1937 classic article, Coase introduces the prototype of the modern notion of "transaction costs"—in his own terminology, "marketing cost"—and defines it as the "costs of using the price mechanism" (1937: p. 390). Coase asserts that the emergence of the firm is attributable primarily to the existence of such costs since certain "marketing cost" can be saved by forming firm-like organizations. However, Coase's treatment of this concept, in many ways, is rather ambiguous. Above all, the definition provided by Coase, as has been criticized by so many (e.g., Allen, 1999; Schlag, 1989), is somewhat tautological. It is true that Coase goes further to list a few concrete categories of "marketing cost"[1], but to define an abstract term by enumerating its concrete empirical counterparts is logically imperfect, since any

[1] In providing examples of what he meant by "market costs", Coase mentions the costs of discovering what the relevant prices are; the costs of negotiating and closing a contract; and he even hints at the costs associated with the problem of enforcement.

enumeration is unlikely to be complete. Accordingly, the generality and precision of the definition could be legitimately doubted. Relatedly, by reserving the term "marketing costs" to those costs incurred only in market exchange (i.e., using the price mechanism), Coase leads a reader to the wrong impression that transaction costs arise only in market exchange. Admittedly, in various passages, Coase does implicitly suggest that transaction costs could be internal to the firm and not just market costs, and he even hints that these two sub-categories of transaction costs can be examined consistently through the lens of contract, but he stops short of making the point explicit and ultimately leaves the issue open for interpretation.

In retrospect, Coase's seminal analysis was neglected for more than three decades in the sense that although its existence is well-known (much cited), the line of reasoning contained in this article is seldom followed and further explored (little used) (N. J. Foss, Lando, & Thomsen, 1999). The publication of the paper, for quite a long time, did not give rise to a follow-on theory development. One scholar even labelled this as "a strange fact of economic history" (Allen, 1999, p. 896). However, it seems to the author that this is far from being surprising and it could, to a large extent, be attributed to the ambiguity surrounding the concept of "transaction costs". To Hart and Holmström, who are both prominent contributors to the transaction cost literature, the term is admittedly "a notoriously vague and slippery category" (Hart & Holmstrom, 1987: p. 132). To some more critical authors, "transaction costs have a well-deserved bad name as a theoretical device ..... because there is a suspicion that almost anything can be rationalized by invoking suitably specified transaction costs" (Fischer, 1977: note 5), and the term has evolved to the point that it can "include any cost that is convenient and elusive enough to avoid critical examination"(Niehans, 1987: p. 678).

Given the fact that at the time when Coase wrote this article most of the knowledge[2] that paved the way for a systematic understanding of transaction costs was not available to theorists (N. J. Foss & Klein, 2006), it would be unfair to blame Coase for his failure to articulate a clear-cut definition.

2.1.2 Coase (1960)

As mentioned above, for quite a long period after the publication of "The Nature of the Firm", neither Coase, nor any other economists seems to show significant interest in the theme of transaction costs. By the end of 1950's, Coase picked up the topic

[2] See Foss & Klein (2006) for a nice coverage of the "advance in tooled knowledge" related to the theory of the firm from 1950s to 1970s.

again, first in "The Federal Communications Commission" (Coase, 1959), and then more explicitly in the "The Problem of Social Cost" (Coase, 1960). The essence of the later article has often been summarized as the "the Coase Theorem" (Stigler, 1966, p. 113) which makes a connection between transaction costs and property rights in the context of the common law of liability. The theorem has been expressed in various ways and a recent version (Allen, 1999: p. 897) states that: "[I]n the absence of transaction costs, the allocation of resources is independent of the distribution of property rights."

The implications of this paper are profound (Medema & Zerbe, 1999). For our purpose, it is sufficient to emphasize the following points. First of all, Coase (1960) provided a more detailed exposition of the costs of market transactions[3]. However, such exposition did not go beyond giving examples in the "and so on" style, as he did in his 1937 article. Moreover, the text of Coase (1960) —especially the few passages in which he directly discusses the costs of market transactions—again leads a reader to the wrong impression that transaction costs arise only in market exchange. In other words, Coase did not take the chance to show the consistency of transaction costs under different institutional arrangements, whether they be "costs involved in carrying out market transactions"(Coase, 1960: p. 10), or "administrative costs" (Coase, 1960: p. 11) internal to the firm. Nevertheless, the publication of the "The Problem of Social Cost" infused a renewed interest to this theme and related fields in the next few decades, and it is widely acknowledged that one of the seminal contributions of this article is to establish a direct linkage between transaction costs and property rights. Somewhat surprisingly, even Coase did not fully realize this accomplishment at the time of writing[4] (Allen, 1999).

2.1.3 Arrow (1969)

It took the economics profession quite some time to realize the point Coase made in his 1960 article—i.e., property rights and transaction costs are fundamentally interlinked and they are in fact two sides of the same coin. When realizing this, some generalized definitions of transaction costs began to take shape, among which the

[3] This time, Coase identifies the costs of market transaction as those "to discover who it is that one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading up to a bargain, to draw up the contract, to undertake the inspection needed to make sure that the terms of the contract are being observed and so on." (Coase, 1960, p. 15)

[4] In his Nobel Prize lecture (1992), Coase stated that:

> "I should add that in writing this article I had no such general aim in mind. I thought that I was exposing the weaknesses of Pigou's analysis of the divergence between private and social products, an analysis generally accepted by economists, and that was all. It was only later, and in part as a result of conversations with Steven Cheung in the 1960's that I came to see the general significance for economic theory of what I had written in that article…"

one given by Kenneth Arrow (1969) was probably the first. According to Arrow, "*transaction costs are costs of running the economic system*" (Arrow, 1969/1983: p. 134, emphasis added) and "the identification of transaction costs in different contexts and under different systems of resource allocation should be a major item on the research agenda of … resource allocation in general" (Arrow, 1969/1983: p. 134). He further indicated that a few dimensions might be of particular relevance to the identification of transaction costs. In retrospect, these few dimensions have included almost all the basic elements of the current understanding of transaction costs.

First of all, in Arrow's view, transaction costs and production costs are two distinct categories. According to Arrow, "the distinction between transaction costs and production costs is that the former can be varied by a change in the mode of resource allocation, while the latter depend only on the technology and tastes, *and would be the same in all economic systems*" (Arrow, 1969/1983: p. 149, emphasis added). Put differently, in Arrow's view, the choice of institutions affects transaction costs only but not production costs. This argument has been extraordinarily strong and the grounds for its justification could be reasonably doubted. For now, it would be sufficient to note that the production costs (transformation costs)/transaction costs dichotomy (Wallis & North, 1986) in the transaction costs literature is seemingly first introduced by Arrow, which, in turn, leads to an undue partition between transaction costs and production costs. Surely, it would be misleading to assert that the modern transaction cost literature depicts production as totally unaffected by the choice of institution. However, as pointed out by Langlois and Foss (1999), in this literature, there is an unjustified partition between transaction costs and production costs. Specifically, by adopting a pragmatic methodological postulate—i.e., holding production costs constant across alternative modes of organization and looking only at transaction costs—this literature tends to focus exclusively on how the choice of alternative modes of organization might affect transaction costs, while the possibility that organization might also have an impact on production costs is rarely considered.

Secondly, Arrow suggested that one type of transaction costs can be related to the problem of externality in general and to what Richard Musgrave (Musgrave, 1959) called the "exclusion principle" in particular. More specifically, the exclusion principle implies that "pricing demands the possibility of excluding nonbuyers from the use of the product, and the exclusion may be technically impossible or may require the use of considerable resources" (Arrow, 1969/1983: p. 146). He concluded that "exclusion costs" is "a limiting case of one kind of transaction costs" (Arrow, 1969/1983: p. 134).

More importantly, by referring to the economics of information literature, Arrow identified "the costliness of the information needed to enter and participate in any market" (Arrow, 1969/1983: p. 134) as a predominant source of transaction costs. Admittedly, Coase did list the cost of "discovering what the relevant prices are" (Coase, 1937: p. 390) as an item of transaction costs which is suggestive of the value of information. However, given the time of his writing—1937, a time when the scholarship in information economics did not even took shape—it is less likely that Coase would have a thorough understanding of the linkage between transaction costs and information structure. Arrow noted that the relation between information structure and transaction costs "has received little attention" (Arrow, 1969/1983: p. 134), possibly due to the fact that "the whole subject is in its infancy" (Arrow, 1969/1983: p. 144) at that time, and he then tried to establish the possible linkage between the two.

Arrow pointed out first that "*information is closely related on the one hand to communication and on the other to uncertainty*" (Arrow, 1969/1983: p. 134, emphasis added). Before Arrow, Marschak (1968) investigated to some extent the costs of communication in the context of decision making[5]. Arrow further elaborated the following: (a) the fact that lack of necessary information would eliminate opportunities for mutually favourable exchanges also means that "there is an economic value in transmitting information from one agent to another, as well as in the creation of new information" (Arrow, 1969/1983: p. 144); (b) "the transmission of information is not costless" (Arrow, 1969/1983: p. 144), while the physical costs of transmission would probably be non-negligible, the major costs of transmission are those invested in "the 'coding' of the information for transmission and the limited channel capacity of the recipients." (Arrow, 1969/1983: p. 144); (c) "the costs of transmitting information vary with both the type of information transmitted and the recipient and sender" (Arrow, 1969/1983: p. 144). "The first point implies a preference for inexpensive information" and "the second point is relevant to the value of education and to difficulties of transmission across cultural boundaries" (Arrow, 1969/1983: p. 144); (d) "because the costs of transmission are non-negligible, even situations which are basically certain become uncertain for the individual" (Arrow, 1969/1983: p. 144).

[5] Marschak (1968) suggested that the process of decision making could be regarded as a sequence of transformations of one type of information into another; he further identified three major stages of transformation (what he called "transformers"): inquiring (data collection), communicating (message transmission), and deciding (computation). Informational costs may be attached to each of these transformers.

Given the focus of this section (the evolution of the concept of "transaction costs", which relates mainly to the transaction costs literature), I refrain from detouring into other branches of literature. However, a few brief remarks can be made here. Any reader of the above quotations, if he is familiar with the resource-based/knowledge-based literature, would probably think of such terms as "codifiability", "familiarity", "transferability" of knowledge across organizational/cultural interfaces, "common language", "organizational learning" and so on. To be more exact, what Arrow referred to as "costs of transmitting/ communication" are indeed costs associated with ***coordination*** in a world of ***incomplete information*** and ***bounded rationality*** (cognition), rather than costs associated with ***incentive conflicts*** in a world of ***asymmetric information*** and ***opportunistic behaviour***—which has been the exclusive focus of the transaction cost literature. Accordingly, the major relevance and impact of these points, as we will see later, has been in the knowledge based literature rather than in the transaction cost literature.

I now go back to the second linkage between transaction costs and information as indicated by Arrow, i.e., how "uncertainty"[6] might affect transaction costs. Arrow noted that the presence of pure risk might not be a serious challenge for the existence of a competitive equilibrium, since market participants "can make contracts contingent on the occurrence of possible states" (Arrow, 1969/1983: p. 142). However, in the face of "uncertainty", "no contingent contract can be made if, at the time of execution, either of the contracting parties do not know whether the specified contingency has occurred or not" (Arrow, 1969/1983: p. 142). Moreover, Arrow suggested that "*the critical impact of information on the optimal allocation of risk bearing is not merely its presence or absence but its inequality among economic agents*" (Arrow, 1969/1983: p. 143, emphasis added). He differentiated two generic situations in which "differential information"[7] might have an impact on the working of the market and the transaction costs—i.e., "adverse selection"[8] and "moral

[6] It should be emphasized that what Arrow described as "uncertainty" here is different from the deep "uncertainty" in the Knightian sense. As would be evident below, Arrow was in fact discussing how asymmetric information might affect transaction costs.
[7] The corresponding standard terminology nowadays should be "asymmetric information".
[8] In the "adverse selection" case, the choices of the informed agent depend on her private information in a manner that adversely affects uninformed market participants. The prototype of the "adverse selection" story is a situation in the life insurance market in which the insured knows their risks better than the insurance company. The insurer starts by charging rates on some actuarial basis. But under this rate, the high-risk groups will buy more of the insurance than the average, while the low-risk groups will buy less. Hence, the economic profit of the insurance company will be less favourable than it expects, which is based on the actuarial calculation and the assumption that there is a pooling equilibrium. The rates will have to be raised, but this in turns will drive more of the low-risk groups out. If such a vicious circle goes on, this market might ultimately be destroyed.

hazard"[9]. Each of the stories is now well-known. What might be worth mentioning is that, to a large degree, the above classification, together with Arrow's subsequent contributions[10] (Arrow, 1985), has basically shaped the modern taxonomy of "asymmetric information" models (Bolton & Dewatripont, 2005; Hart & Holmstrom, 1987; Laffont & Martimort, 2002; Mas-Colell, Whinston, & Green, 1995; Rasmusen, 2006), which generally differentiates between "adverse selection", "moral hazard models" and "non-verifiability (incomplete contract) models" (see Table 2-1). Moreover, it seems that Arrow also leads the tradition in the more technical literatures[11] by which the transaction costs are described as a situation in which the underlying information structure has made the transaction difficult rather than as concrete costs under any substantiated heading[12].

In summarizing how the lack of necessary information might have an impact on "transaction costs", Arrow concludes that "costs of communication and information, including both the supply and the learning of the terms on which transaction can be carried out" (Arrow, 1969/1983: p. 149) is one of the important "sources of transaction costs".

Finally, Arrow identified "the costs of disequilibrium" (Arrow, 1969/1983: p. 149) as a third source of transaction costs. According to Arrow, "in any complex system, the market or authoritative allocation, even under perfect information, it takes time to compute the optimal allocation, and either transactions take place which are inconsistent with the final equilibrium or they are delayed until computations are completed" (Arrow, 1969/1983: p. 149). Costs arising in this connection can be placed under this category.

To sum up, Arrow's contributions to the refinement of the concept of "transaction costs" can be summarized as follows. Firstly, Arrow makes it clear explicitly —for

[9] Arrow (1969) describes the "moral hazard" situation as a case in which "one agent can observe the joint effects of the unknown state of the world and of decisions by another economic agent, but not the state or the decision separately" (Arrow, 1969/1983: p. 143), consequently, there would be a "a confounding of risk and decision" (Arrow, 1969/1983: p. 143). A typical example of "moral hazard" is that of fire insurance. The insurer can easily observe whether a fire has occurred or not, but he cannot, without special investigation, know whether the fire was due to causes exogenous to the insured or due to the insured's decisions (on purpose, or negligence). The general effect of the case is that once someone has been insured against adverse final outcomes, his incentive to good decision making will be automatically reduced.

[10] In Arrow (1985), he further suggests that to differentiate different models, it is crucial to ask what the information structure under consideration is, he then related "adverse selection" to "hidden information", and "moral hazard" to "hidden actions".

[11] These literatures are labelled with various names, interrelatedly and overlappingly: contract theory, mechanism design, formal agency literature and economics of information.

[12] Most of this literature tends to avoid the term "transaction costs".

the first time in the literature—that transaction costs exist not only in market transaction, rather, they are "attached to any mode of resource allocation" (Arrow, 1969/1983: p. 149) and should be deemed as the "costs of running the economic system" (Arrow, 1969/1983: p. 134) which are prevalent in any institution[13]. Secondly, although Arrow does not refer directly to the term of "property rights", what he called "exclusion costs" is strongly suggestive that such costs can be related to the delineation and protection of property rights. Thirdly, by referring to the economics of information literature, Arrow identified the costliness of information as one of the major sources of transaction costs. He further suggests that such information costs can be observed either through the lens of communication, or through the lens of "uncertainty" (asymmetric information). As is clear now, these two lenses, respectively, have rich implications for coordination problems and incentive problems in the organization; and the basic taxonomy of models of "asymmetric information" in the more technical literature, to a large extent, was shaped by Arrow (1969). Finally, as a whole, the definition provided by Arrow—as well as the few dimensions he indentified as being particularly relevant to the identification of transaction costs—are at a high level of theoretical abstraction. Such definition and understanding has obviously gone beyond the less satisfactory way of enumerating limited examples of real-world headings of transaction costs, and has seemingly included almost all the basic elements of the contemporary understanding.

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[13] Note that the understanding is very similar to that of Steven Cheung, who writes that: "***with the full approval of Coase***, the transaction cost should actually be called 'institution cost" (Cheung, 1998/2005: p. 103, emphasis added).

Table 2- 1: Taxonomy of "Asymmetric Information Models"[14]

	Information structure	*Sub-categories and representative literature*
Adverse Selection Models	Asymmetric information at the stage of contracting negotiation and also during the contract period.	1. Basic adverse selection model (with ex ante hidden information) To certain extent, markets and institutions evolve and develop some mechanisms to reveal information and overcome adverse selection problems, at least partially. Two such responses can be identified: market signalling and market screening. Sub-categories of adverse selection models are thus differentiated. (Bolton & Dewatripont, 2005; Hart & Holmstrom, 1987; Laffont & Martimort, 2002; Mas-Colell et al., 1995; Rasmusen, 2006) 2. Adverse selection with screening: Uninformed market participants can design offers in such a way that an informed agent would self-select the offer that is best for him, which then reveals his type in equilibrium. (Akerlof, 1970) 3. Adverse selection with signalling: The informed market participants take certain actions to reveal private information. (Rothschild & Stiglitz, 1976)
Moral hazard models	Information is symmetric among the involved parties at the stage of contracting but asymmetric afterwards during the persistence of relationship.	1. Moral hazard with hidden action: The agent takes an action that cannot be observed by the uninformed party. The uninformed party observes only a noisy signal of the action. (Spence, 1973) 2. Moral hazard with (ex post) hidden information: The informed agent privately observes the realization of the state of the world (after the contract has been signed). The uninformed agent observes the agent's action, but he does not know whether the action is appropriate. (Holmstrom, 1979)
Non-verifiable models (incomplete contract models)	The involved parties are symmetrically informed and observe the state of the world, but they cannot verify it to an outside party, say, the courts.	Grossman & Hart, 1986; Hart & Moore, 1988; Rasmusen, 2006, Ch. 10

Source: Author compilation from various sources.

[14] I am aware that there are different opinions regarding the taxonomy of Asymmetric Information Models. For example, Myerson (1991) argues that 'moral hazard with hidden information' and 'adverse selection' are the same problem and further suggests calling the problem of players taking the wrong action "moral hazard" and the problem of misreporting information "adverse selection." Laffont and Martimort (2002) take a similar position by identifying "moral hazard" with "hidden action" and "adverse selection" with "hidden information". Given the purpose here, the taxonomy I present above is just a rough synthesis of the existing literatures on the status quo basis.

Table 2- 2: Arrow's (1969) Definition and Understanding of "Transaction Costs"

Definition	"*Transaction costs are costs of running the economics systems*" "*transaction costs…are attached to any market and indeed to any mode of resource allocation*"
Components (or the critical dimensions to pin down transaction costs)	Exclusion costs
	Information costs
	Disequilibrium costs

2.1.4 Cheung (1968, 1969a, 1969b, 1970)

At roughly the same time that Arrow wrote the above article, Steven N. S. Cheung published his Ph.D. thesis and there were also a series of papers[15] (Cheung, 1968, 1969a, 1969b, 1970). Though less quoted, these papers have been recognized (Allen, 1999; Barzel, 2001; Coase, 2005) as making important contributions to the refinement of the concept of "transaction costs". In brief, Cheung explicitly relates transaction costs to ***property rights*** and he argues for a ***contractual lens*** by which transaction costs under various situations can be observed consistently. Let me discuss these two points in turn.

As mentioned above, the connection between property rights and transaction costs was first established by Coase (1960), but he was unaware of his accomplishment when he was writing the article[16] and it was "in part as a result of conversations with Steven Cheung in the 1960's"(Coase, 1992) that he came to realize this. In a series of papers, Cheung, probably for the first time in the literature, explicitly relates transaction costs to property rights. Moreover, following Alchian (1965), he has put a strong emphasis on "economic rights" rather than "legal rights" when he used the term "property rights[17]".

These points would be evident in the following paragraph in which Cheung writes:

[15] The first two papers are drawn from Cheung's PhD thesis and published separately as journal articles.
[16] See footnote 4 of this chapter.
[17] Alchian defines property rights as "the rights of individuals to the use of resources" (Alchian, 1965, p. 817)

> "If a firm can increase efficiency in production by employing productive resources of more than one resource owner, a contract to combine the resources will obtain. The formation of the contract involves *partial transfers of property rights* in one form or another, such as leasing, hiring or mortgaging. *These transfers*, and the associated coordination of inputs of various factors in production, *are costly events. There are costs of negotiating and of enforcing the stipulations of the contract*." (Cheung, 1969b: p. 24-25, emphasis added)

Clearly, the above paragraph views the firm as a contractual entity, the formation of which involves the transfers of property rights and there being costs associated with negotiating and enforcing contracts for such transfers.

Relatedly, Cheung explicitly suggests a contractual lens by which transaction costs under various "institutional arrangements" could be examined consistently. Surely, this idea could be traced back to Coase (1937) for some hints, but Cheung argues explicitly that, to a large extent, the consistency of transaction costs under various situations—be they arising from market exchange, or from internal organization—lies in that they could all be deemed as "***contracting costs***". According to Cheung, "included in the general term 'contracting cost' are the costs of negotiating and the costs of enforcing the stipulations of the contract[18]"(Cheung, 1969a, p. 16, footnote 1). Viewed in the lens of transaction costs as contracting costs, Cheung concludes that:

> "A second [19] reason for the existence of different contractual arrangements lies in the different transaction costs that are associated with them. *Transaction costs differ because the physical attributes of input and output differ, because institutional arrangements differ, and because different sets of stipulations require varying efforts in enforcement and negotiations*."(Cheung, 1969b: p. 24-25, emphasis added)

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[18] Later In chapter 4 (Cheung, 1968a), Cheung further explains that enforcement costs are the "costs of controlling inputs and distributing output, according to the terms of the contract."

[19] Cheung lists "the existence of natural risk" (Cheung, 1969b) as the first reason for the existence of different contractual arrangements. Natural risk, as defined by Cheung, is "the contribution by nature or the state of the world to the variance (or standard deviation) of the product value" (Cheung, 1969b, p.24) and the existence of different contractual arrangements could be justified in terms of their different risk-pooling attributes. In Cheung's own parlance "given a non-zero variance for the expected output yield (the total income for the contracting parties), different contractual arrangements allow different distributions of income variances among the contracting parties" (Cheung, 1969b, p.24).

As we will see later, this conclusion is close to the now dominant Williamson's view[20] (Williamson, 1975, 1985a, 1996c) that different governance mechanisms of contractual relation are chosen to economize on transaction costs which in turn depend on a few critical dimensions of transactional attributes.

Pushing this line of reasoning still further, Cheung, in his 1970 paper, provides a generalized definition in which both the element of "property rights" and "contracting costs" are combined. According to Cheung (1970):

> "The costs associated with the formation of property and of the subsequent contracts may be viewed in two stages. At one stage, without exchange, there are costs of defining and policing exclusivity. These costs vary, among other things, according to the physical attributes of the resource in question. ...... At a second stage, there are costs associated with negotiating and enforcing contracts for the exchange or transfer of property rights. …… For these reasons it is convenient, although somewhat arbitrary, to lump the costs at the two stages into one broad term, namely, transaction costs."(Cheung, 1970, p. 67-68)

Cheung further emphasises that these two categories are interdependent, thus they should be considered together.

2.1.5 Dahlman (1979)

A similar[21] but more extended and more influential definition can be found in Dahlman (1979) which states:

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[20] Williamson would probably agree on this point. In Williamson (1985, p. 4, footnote 4), when commenting on Cheung's (1983, p. 4) contention that "Coase's argument is…not tautological if one can identify different types of transaction and how they will vary under different circumstances", he concurs that "this is correct", but then he points to the fact that "such discriminating effort was not prescribed by Coase, and such a need went unorganized until vertical integration was expressly explicated in transaction cost terms (Williamson, 1971)."
One more comment could be made in this regard. It is true that Coase did not provide any prescription on "discriminating alignment". But it seems to me that the credit of articulating such an prescription, or at least the credit of recognizing the need to make such discriminating efforts, should probably go to Cheung (1969b). In fact, the point made in Cheung (1969b) is more articulated than the passage in Williamson (1971).

[21] The two definitions are similar in that both of them draw on the notion of "property rights" and view transaction costs as evolving around different phases of the contracting process.
Dahlman does not refer to Cheung, rather, his discussion refers primarily to Coase (1960) and also to Arrow (1969) on some occasions. Thus, the two definitions should be deemed as being developed independently but probably could be traced back to roughly the same sources.

> "In order for an exchange between two parties to be set up, it is necessary that the two search each other out, which is costly in terms of time and resources. If the search is successful and the parties make contact they must inform each other of the exchange opportunity that may be present, and the conveying of such information will again require resources. If there are several economic agents on either side of the potential bargain to be struck, some costs of decision making will be incurred before the terms of trade can be decided on. Often such agreeable terms can only be determined after costly bargaining between the parties involved. After the trade has been decided on, there will be costs of policing and monitoring the other party to see that his obligations are carried out as determined by the terms of the contract, and of enforcing the agreement reached. These, then, represent the first approximation to a workable concept of transactions costs: search and information costs, bargaining and decision costs, policing and enforcement costs." (Dahlman,1979: p. 147-148)

In brief, the functional taxonomy of different categories of (Coasian) transaction costs elaborated by Dahlman can be summarized as table 2-3. Dahlman goes on to argue that "fundamentally, the three classes reduce to a single one—for they all have in common that they represent resource losses due to lack of information" thus "it is really necessary to talk only about one type of transaction cost: resource losses incurred due to imperfect information."(Dahlman, 1979: p. 148)

Above, we identify the few critical steps in the evolution of the concept of transaction costs. These few steps are marked by the publication of a series of papers from 1930s to 1970s. Specifically, these papers are: Coase (1937), Coase (1960), Arrow (1969), Cheung (1969a; 1969b; 1970) and Dahlman (1979). It should be noted that at least by the end of 1970s, there seems to be a consensus that transaction costs should be understood (1) as the costs of institutions, which universally exist in any mode of resource allocation; (2) through the lens of contract, around different phases of which transaction costs evolve; (3) with a connection to property rights since they are two sides of the same coin; and (4) as resulting from "lack of information" and to a large extent, reducible to information costs.

Table 2- 3: Dahlman (1979)'s Definition of Transaction Costs–A Functional Taxonomy of Transaction Costs as Evolving around Different Phases of the Contracting Process

Categories of Transaction Costs	Search and information costs
	Bargaining and decision costs
	Policing and enforcement costs

2.2 Different Approaches within Transaction Costs Economics and Their Respective Contributions to the Understanding of Transaction Costs

On the basis of the above development, together with other parallel advancement in related areas, serious work on the theory of the firm began in the 1970s and 1980s (N. J. Foss, 2000b), first evident in two seminal contributions by Williamson (1971) and Alchian & Demsetz (1972), then marked by the expanding branching of distinct approaches under the same label of "Transaction Costs Theory of the Firm", or more generally, "New Institutional Economics". Though all these different approaches share some common themes, characteristics and modelling heuristics, they are far from being homogeneous. For our purpose, it is sufficient to note that even though there is some consensus regarding how the term "transaction costs" should be understood—as I just illustrated—each of the approaches has put quite different emphasis when applying the transaction cost reasoning to explain the existence, boundary determination or internal organization of the firm. In doing so, the once "slippery" concept has been further clarified, refined and operationalized, and our understanding is enriched accordingly.

Below, I review some of the major contributions made by these approaches which have furthered our understanding of "transaction costs".

As a first approximation, a classification of the different approaches within "New Institutional Economics" suggested by Williamson (1985) might be useful for our purpose.

Williamson argues, unlike the *monopoly approach* to contract, which ascribes complex forms of contracting—or more generally, any departures from the classical norm—to monopoly purposes, the *efficiency approaches* "hold that the departures serve economizing purposes instead" (Williamson 1985, p. 23). He further differentiates the efficiency approaches into two branches, i.e., ***the incentive branch*** and ***the transaction costs branch***. For the incentive branch, there are ***the property***

rights approach and ***the agency approach***, while the transaction costs branch is split into ***the measurement approach*** and ***the governance approach***. (see figure 2-1).

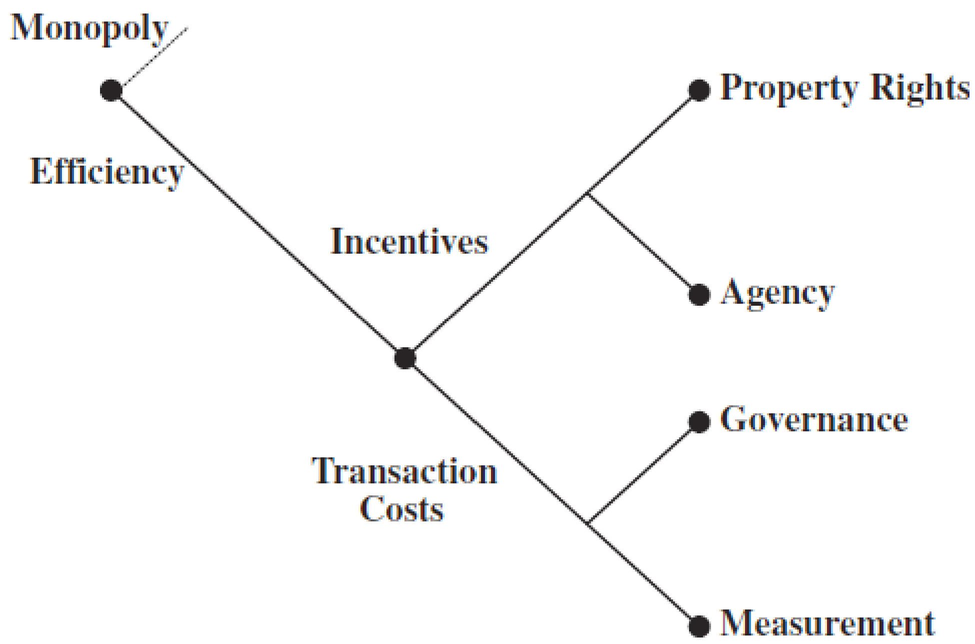

Figure 2- 1: Williamson's "Cognitive Map of Contract": The Efficiency Side

Source: Figure 1-1, Williamson (1985: p. 24)

Based on this classification, the following review will be organized in two parts.

In the first part, we review the most representative literature in the each of first three approaches (i.e., the property rights approach, the agency approach, and the measurement approach), focusing on their respective contributions to the understanding of transaction costs.

Given that Williamson's approach has been dominant in the theory of the firm, a separate subsection will be devoted to a review of Williamson's understanding of "transaction costs".

Such an arrangement can be further justified if one notes that the first three approaches could each be deemed as an outgrowth of Alchian & Demsetz (1972).

Being one of the most cited papers in the history of economics, the paper is widely recognized as a classic contribution to the property rights approach in which the authors argue forcefully that property rights matter as they establish the institutional context within which transactions are negotiated, and that structure/distribution of property rights has a significant impact on agency and transaction costs (Joseph T. Mahoney, 2005). Moreover, this paper inspires other seminal work. Specifically, in the context of the "team production" problem, this paper simultaneously addresses the triple issues of *property rights and incentive alignment*, *agency problem*, and *metering problem* which correspond exactly to themes of the property rights approach, the agency approach and the measurement approach respectively.

2.2.1 The Property Rights Approach, The Agency Approach and The Measurement Approach

A. Alchian & Demsetz (1972) and the Property Rights Approach

Given the pivotal position of this paper in the above classification and indeed in the economic theory of the firm, the subsection covers a critical evaluation of the paper's contributions and shortcomings.

Alchian and Demsetz start by challenging explicitly the Coasian view that the firm is "characterized by the power to settle issues by fiat, by authority, or by disciplinary action superior to that available in the conventional market" (Alchian & Demsetz, 1972, p. 777). In their view, the distinction between the authority-based and price-based modes of allocation is superficial, or a "delusion". In reality, they argue, the relationship between employers and employees is identical to that existing between shoppers and their grocers in fiat and authority respects:

> "The single consumer can assign his grocer to the task of obtaining whatever the customer can induce the grocer to provide at a price acceptable to both parties. That is precisely all that an employer can do to an employee. To speak of managing, directing, or assigning workers to various tasks is a deceptive way of noting that the employer continually is involved in renegotiation of contracts on terms that must be acceptable to both parties. Long-term contracts between employer and employee are not the essence of the organization we call a firm." (Alchian & Demsetz, 1972, p. 777)

In short, there is no basic difference between "firing" one's grocer and firing one's secretary, and what looks like a long, open-ended employment contract is nothing more than a cover for a continuous process of implicit negotiation between employer and employees.

Having denied the employment relationship as the defining feature of the firm-like organization, they then identify ***"team production" with a centralized contractual agent*** as the essence of the firm. According to them, team production is:

> "……production in which (1) several types of resources are used and (2) the product is not a sum of separable outputs of each cooperating resource. An additional factor creates a team organization problem: (3) not all resources used in team production belong to one person." (Alchian & Demsetz, 1972, p. 779)

The first and the second point can be put more formally.

The production function of the team can be written as:

$$Y = f(x_1, x_2, \cdots, x_n) \tag{2.2.1}$$

where $x_1, x_2, \cdots, x_n$ are the inputs.

However, Y can not be expressed as $\sum_{i=1}^{n} f_i(x_i)$, where f_i is a function of x_i.

This is the case because at least one second order partial derivatives of the production function is greater than zero, i.e.:

$$\exists\, x_i, x_j \in (x_1, x_2, \cdots, x_n),\ \partial^2 Y / \partial x_i \partial x_j > 0 \tag{2.2.2}$$

which means the marginal contribution of at least one input depends on some other input (i.e., the marginal contributions are not always independent). In plain language, there are complementary effects between the inputs.

However, the characteristics of team production, as illustrated above, just imply that "there is a source of gain from cooperative activity involving working as a team" (Alchian & Demsetz, 1972, p. 779), and team production might potentially be used if it yields an output sufficiently larger than the sum of separable production of each input to cover the costs of organizing and disciplining team members. But why should a central agent emerge in the contractual arrangements of all other inputs? Alchian and Demsetz provide their answer by referring to what they call the "metering problem".

According to them, "***meter means to measure and also to apportion***" (Alchian & Demsetz, 1972: p. 778, footnote 1)—i.e., the word is used to denote the measurement of output (or more exactly, the measurement of the contribution to output) as well as the distribution of rewards. The metering problem is at the heart of efficient incentive alignment because the efficiency of different modes of economic organization depends on the extent to which a mode can align incentives correctly, while the right incentive alignment requires a correct measurement of the marginal productivity of each cooperating resource owner as well as a correct apportionment of rewards. They note that the metering costs are assumed to be zero in "classical analysis of production and distribution" (Alchian & Demsetz, 1972: p. 778), which, in their view, has left out some important issues. They further suggest that if we bring the case of positive metering costs to the fore, "the economical means of metering productivity and rewards" (Alchian & Demsetz, 1972: p. 779) might provide some clues to the choice of economic organization.

As illustrated above, in the case of team production, "the marginal products of cooperative team members are not so directly and separably (i.e., cheaply) observable" (Alchian & Demsetz, 1972: p. 780) and "individual cooperating inputs do not yield identifiable, separate products which can *be summed to* measure the total output" (Alchian & Demsetz, 1972: p. 779, emphasis in the original). As a result, "measuring marginal productivity and making payment in accord therewith is more expensive by an order of magnitude than for separable production functions" (Alchian & Demsetz, 1972: p. 779). In this circumstance, due mainly to the metering difficulty, the potential gains from cooperative activities involving working as a team are unlikely to be organized through ordinary market contracting in which the rewards are based on the direct measurement of the output.

This conclusion can be illustrated formally as follows (Holmstrom & Tirole, 1989).

If the marginal products cannot be observed directly so that rewards must be based on joint output alone—i.e., if the production is characterized by an inseparable individual production function, there is a free-rider problem since team-production can be a cover for shirking. And the socially optimal level of effort can not be induced through market contracting.

Without loss of generality, suppose the technology is given as

$$Y = f(a_1, a_2) \qquad (2.2.3)$$

where, a_1 and a_2 are the effort levels of two team members, measured in effort cost units, and $\partial^2 Y / \partial a_1 \partial a_2 > 0$ which means there is a positive complementary effect between the effort levels of the two members so that there are potential gains from cooperation.

The socially efficient outcome can be obtained via:

$$\underset{a_1, a_2}{Max}\, f(a_1, a_2) - a_1 - a_2 \tag{2.2.4}$$

Solving the maximization problem, we have:

$$f'_{a_1} = f'_{a_2} = 1 \tag{2.2.5}$$

Now, let $s_1(Y)$ and $s_2(Y) = Y - s_1(Y)$ be the rules set for market contracting by which the joint output is divided between the two partners[22].

Further assume that these rules are differentiable. In a non-cooperative equilibrium, the problem facing the two team members are:

$$\underset{a_1}{Max}\, s_1(Y) - a_1 \tag{2.2.6}$$

and

$$\underset{a_2}{Max}\, s_2(Y) - a_2 \tag{2.2.7}$$

respectively.

Solving these two optimization problems, we have

$$s'_1 f'_{a_1} = s'_2 f'_{a_2} = 1 \tag{2.2.8}$$

For this equilibrium to coincide with the socially efficient outcome, it must be that:

$$s'_1 = s'_2 = 1 \tag{2.2.9}$$

[22] Remember that rewards must be based on joint output alone and the total output is divided between the two.

But this cannot be, because $s_2(Y) = Y - s_1(Y)$ implies $s_2' = 1 - s_1'$.

Having excluded market contracting as a viable solution for overcoming the problem, Alchian and Demsetz argue that "the costs of metering or ascertaining the marginal products of the team's members is what calls forth new organizations and procedures" (Alchian & Demsetz, 1972: p. 780). In their view, if the marginal products of cooperative team members are not directly observable and the relative performances of each member are hard to disentangle, a natural alternative to secure the clues to each input's productivity is to observe the behavior of individual inputs—i.e., to monitor ***behaviour*** rather than to meter marginal product directly. Alchian and Demsetz admit that such a switch does not eliminate metering difficulty, it just changes the parameter by which each member's productivity is metered and rewarded. As long as there is a cost associated with detection, policing, monitoring, measuring, or metering, a team member would always have an incentive to take more leisure and shirk working, since part of the consequence will be borne by others in the team (as in their example of jointly lifting heavy cargo into trucks). This, in essence, is a typical case where non-separabilities create a free-rider problem.

Alchian & Demsetz then propose their solution to the problem. In their view, by the specific distribution of property rights known as "the classical firm", the costs of detecting 'performance' can be lowered and the members of a team can be rewarded and induced to work efficiently. More specifically, they argue that "one method of reducing shirking is for someone to specialize as a monitor to check the input performance of team members" (Alchian & Demsetz, 1972: p. 781)—i.e., to introduce a third party who specializes in monitoring the behaviour of the team members. But an ensuing problem would be—how is the monitor monitored? To solve this dilemma, they suggest that the monitor should be given the "title to the net earnings of the team, net of payments to other inputs" (Alchian & Demsetz, 1972: p. 782). In contemporary terminology, the supervisor/monitor is made the ***residual claimant***, thus he has a strong incentive "not to shirk as a monitor" (Alchian & Demsetz, 1972: p. 782). Alchian & Demsetz conclude that the few things which Coase has listed as the defining features of the firm—long-term employment contract, authority, fiat etc.—might miss the point; rather, it is

> "this entire bundle of rights, (1) to be a residual claimant; (2) to observe input behavior; (3) to be the central party common to all contracts with inputs; (4) to alter the membership of the team; and (5) to sell these rights, that defines the ownership (or the employer) of the classical (capitalist, free-enterprise) firm. The coalescing of these

> rights has arisen, our analysis asserts, because it resolves the shirking-information problem of team production better than does the non-centralized contractual arrangement" (Alchian & Demsetz, 1972: p. 783)

Summing up, Alchian and Demsetz's "firm" is *a specific distribution of property rights*, a policing device employed in the presence of team production in which the monitor is made the central party common to all contracts with other cooperative inputs—the one who has the exclusive power to direct team production, to observe the behaviour of other team members and to enjoy the residual claims. Thus, the firm is explained in terms of the reduction of post-contractual measurement cost (N. J. Foss & Klein, 2008a; Tirole, 1988).

However, as has been pointed out by various authors, the simple story of the owner-monitor has a number of problems. Above all, it is not totally convincing why the monitor must be the residual claimant of the firm where he performs his monitoring services (Holmstrom & Tirole, 1989), he can be the employee of the firm, specialized in monitoring services. Similarly, it is also not clear why the employees can not monitor each other (N. J. Foss, 2000b), as in the case of partnerships and cooperatives. As argued by Williamson (1975), due to the scarcity of attention, a monitor can supervise only a limited number of employees[23]; therefore, Alchian & Demsetz's story can at best explain organization of small entrepreneurial firms. Given that modern corporations are characterized by the separation of ownership and control where those who undertake the monitoring are rarely the residual claimants (Holmstrom & Tirole, 1989), their story can in fact be seriously doubted. This point has been further elaborated by Holmstrom (1982) where it is shown that such separation may be desirable from an incentive perspective.

Moreover, the starting point of Alchian & Demsetz's theory is the metering difficulty in ***team production***, while in reality, we seem to observe more firms than can be explained by team production (N. J. Foss, 2000b). From a purely monitoring perspective, it is hard to understand why some technologically separable production teams (e.g., conglomerates, unrelated horizontal mergers) would be placed under the unified ownership of a firm.

[23] Of course, one can imagine that with the increase of the number of owner-monitors, they can monitor/supervise more employees. But the major problem is, with a diverse ownership, the owner's incentive to monitor management would be diluted proportionally.

In spite of these problems, Alchian & Demsetz (1972) must be considered as a seminal contribution. For our purpose, its contribution to a deeper understanding of "transaction costs" can be summarized in the following three aspects.

Above all, the paper, for the first time, brings the costs associated with the metering problem to our attention. As we will see below, such costs, further refined as "measurement costs" by Barzel, have been widely accepted as an important subcategory of "transaction costs" and are of particular relevance to the boundary determination of the firm.

Moreover, to Alchian and Demsetz (1972), the "firm" is a device for economizing post-contractual measurements costs. And it can achieve this goal because it provides a better ***incentive*** alignment by reconfiguring the property rights distribution. It seems to the author that the now widely accepted (if not dominant) understanding of the "firm"—which is based squarely on the notion of residual claims and economic rights (as compared to legal rights) —is first articulated by Alchian and Demsetz (1972). On a more abstract level, it also seems to the author that since the publication of this paper, the theme of incentive alignment[24] has gradually arisen as the dominant theme in the theory of the firm. Right or wrong as it might be, for quite a long period following its publication, to understand the firm as a device for economizing transaction costs through better incentive alignment imposed by a specific distribution of property rights has been the dominant line of thinking in the theory of the firm.

Thirdly, according to Alchian and Demsetz (1972), with the formation of the "firm", the difficulty with direct metering of marginal productivity turns into monitoring difficulty, and the metering costs within the firm turn into monitoring costs. In contemporary terminology, the kind of metering problem described by Alchian and Demsetz (1972), is a special case of agent's moral hazard problems in the principal-agent relationship. Viewed in this way, Alchian and Demsetz are seemingly among the first few to point to ***agency costs*** as an important clue in understanding the internal organization of the firm. As we will see later, this line of reasoning is more clearly articulated in Jensen and Meckling (1976), which was inspired by Alchian and Demsetz (1972) and in many ways an extension of Alchian and Demsetz (1972).

Finally, it should be noted in particular that among the three aspects mentioned above, the second aspect is of the most profound impact. Indeed, Alchian and

[24] It is widely recognized that incentives alignment and coordination are the two basic themes in the theory of the firm.

Demsetz have argued for a different rationale for the existence of the firm which is quite independent of Coase (1937). This point would be most clearly observed from the lens of coordination costs/incentive (motivation) costs dichotomy of transaction costs suggested by Milgrom and Robert (1992). Arguably, Coase's explanation for the existence of the firm is ultimately a coordination one: the firm is an institution that economizes on the transaction costs associated with the qualitative coordination in a world of uncertainty, quite irrespective of consideration of incentive conflict (Langlois & Foss, 1997). Alchian and Demsetz's explanation, on the other hand, places almost exclusive emphasis on incentives alignment.

B. The Agency Approach and Agency Costs

It should be emphasized on the outset that only a small proportion of literature under the label of "agency theory" is relevant to our discussion. For our purpose, this subsection will focus narrowly on how a specific category of transaction costs (agency costs) is understood in this literature and on its relevance to the boundary determination and internal organization of the firm.

Largely inspired by Alchian and Demsetz (1972), most of early agency literature (positive theory of agency) is concerned with the principal-agent problem in the context of firm organization (Williamson, 1985c). Therefore, this literature has a direct relation with the theory of the firm (in particular, the internal organization of the firm). By contrast, more recent agency literature (e.g., Laffont & Martimort, 2002) tends to be more formal and mathematical, and is concerned with the general principal-agent problem independent of any particular organization structure. More specifically, this stream of research aims at fixing the problems of asymmetric information in a principal-agent relation by designing complex (non-standard) contracts. As a whole, they are not theories of the firm *per se*. Rather, they should probably be best understood as extensions of the contingent claims contracting literature within the neoclassical tradition (N. J. Foss, 2000b; N. J. Foss et al., 1999), since both assume unbounded rationality, perfect judicial efficacy, and tend to resolve all relevant contracting issues in a comprehensive *ex ante* bargain (Williamson, 1985, p. 28).

In many aspects, Jensen and Meckling (1976) can be viewed as an extension of the Alchian and Demsetz' reasoning to more fully include the agency problem between owners and managers in the context of the separation of ownership and control (N. J. Foss, 2000b), and they don't think team-production is essential to explaining the corporation. In their view, most organizations, including firms, "are simply legal fictions which serve as a nexus for a set of contracting relationships among individuals." (Jensen & Meckling, 1976: p. 310). Agency costs resulting from the principal-agent problem exist pervasively in all the contractual relations which give rise to what we know as the "firm", and such agency costs are independent of team production. Jensen and Meckling (1976) then define in a systematic way the agency costs in the context of the separation of ownership and control within modern corporations. Based on this definition, they further develop a theory of optimal capital structure that minimizes all sorts of agency costs.

Jensen and Meckling (1976) argue that "'separation of ownership and control' in the modern diffuse ownership corporation are intimately associated with the general problem of agency" since "the relationship between the stockholders and the managers of a corporation fits the definition of a pure agency relationship" (Jensen and Meckling, 1976: p. 309), which is "a contract under which one or more persons (the principal(s)) engage another person (the agent) to perform some service on their behalf which involves delegating some decision making authority to the agent" (Jensen and Meckling, 1976: p. 309).

They argue, as long as "both parties to the relationship are utility maximizers, there is good reason to believe that the agent will not always act in the best interests of the principal" (Jensen and Meckling, 1976: p. 308) which gives rise to agency costs. Such costs, they suggest, can be observed from the following dimensions. Above all, "the principal can limit divergences from his interest by establishing appropriate incentives for the agent and by incurring monitoring costs designed to limit the aberrant activities of the agent" (Jensen and Meckling, 1976: p. 308). In addition, "in some situations it will pay the agent to expend resources (bonding costs) to guarantee that he will not take certain actions which would harm the principal or to ensure that the principal will be compensated if he does take such actions" (Jensen and Meckling, 1976: p. 308). And finally, "it is generally impossible for the principal or the agent at zero cost to ensure that the agent will make optimal decisions from the principal's viewpoint" (Jensen and Meckling, 1976: p. 308), accordingly, apart from the monitoring and bonding costs (non-pecuniary as well as pecuniary), "there will be some divergence between the agent's decisions and those decisions which would maximize the welfare of the principal" and such "dollar equivalent of the reduction in welfare experienced by the principal as a result of this divergence is also a cost of the agency relationship, and we refer to this latter cost as the 'residual loss'" (Jensen and Meckling, 1976: p. 308). In short, the agency costs are defined as:

"…the sum of,
1. the monitoring expenditures by the principal,
2. the bonding expenditures by the agent,
3. the residual loss." (Jensen and Meckling, 1976: p. 308)

Using this definition, Jensen and Meckling analyse the agency costs of outside equity and debt, and then define optimal capital structure as the combination of debt and equity that minimizes agency costs. Subsequent contributions (Fama, 1980; Fama & Jensen, 1983a, 1983b) following the same line of reasoning have led to a much deeper understanding of the complex principal-agent network within the firm. As a whole, this stream of literature, which started with Jensen and Meckling (1976), can be described as trying to understand the internal organization (structure) of the firm in terms of minimizing agency costs, and this line of reasoning is probably still the dominant logic on this issue today.

C. Measurement Approach and Measurement Costs

Another branch of literature—measurement costs literature—can also be deemed as an outgrowth of Alchian & Demsetz (1972). This branch of literature, probably best represented by the work of Yoram Barzel (1977, 1982, 1985, 1989, 2001, 2005), is concerned with the category of transaction costs resulting from performance or attribute ambiguities associated with the supply of a good or service, and is of particular relevance to the boundary determination of the firm.

As has been indicated above, the notion of metering difficulty and metering costs are first introduced by Alchian and Demsetz (1972), but their discussion is placed in the specific context of team production. Beyond the context of team production, is metering difficulty still a concern? Are metering costs still of any general relevance to economic organization? Alchian and Demsetz (1972) tend towards a positive answer, and they give some clues[25], but they do not go any further.

[25] According to Alchian & Demsetz (1972), even though they "have emphasized team production as creating a costly metering task and have treated team production as an essential (necessary?) condition for the firm"(p. 785), "***other obstacles to cheap metering***" other than team production would "also call forth the same kind of contractual arrangement here denoted as a firm"(p. 785).
In their example, if wheat is of subtle and difficult-to-detect quality variations, and if such quality variations are determined by how the farmer grew the wheat, vertical integration might be a possible solution in which a purchaser could have a better leverage to control the farmer's behavior in order to more economically estimate productivity. This example does not involve team production, but vertical integration is one of the feasible possibilities. However, to overcome the metering difficulty in this case, there are still other possibilities. As they indicate, "instead of forming a firm, a buyer can contract to have his inspector on the site of production, just as home builders contract with architects to supervise building contracts; that arrangement is not a firm"(p. 785)

Following the clues given by Alchian and Demesetz (1972), Barzel (1977, 1982, 1985, 1989, 2001, 2005) and some other scholars (McManus, 1975; Ouchi, 1980) explore in greater detail the general relevance of measurement costs for economic organization. For our purpose, it will be sufficient to address the following few points.

First of all, although Alchian & Demsetz (1972) admit that metering difficulty might be a general problem, they limit their discussion of metering difficulty and the associated costs to the context of team production. By contrast, McManus (1975)[26] and Barzel argue explicitly that measurement problem and measurement costs are of general relevance, they are independent of team production and exist universally in any transaction. In Barzel's words, "the problems and costs of measurement pervade and significantly affect all economic transactions" (Barzel, 1982: p. 48). This is the case because "people will exchange only if they perceive what they get to be more valuable than they give", but "to form such perceptions, the attributes of the traded items have to be measured" (Barzel, 1982; p. 27). In other words, people participate in exchange with an aim to improve on the utility level they enjoy, and what ultimately brings about the utility, are the attributes of the traded item. However, these attributes, in general, may not easily be measured. Some resources have to be spent on the measurement of the desired attributes. Barzel then contends that measurement costs should be understood in a broader sense as the costs of *measuring the desired attributes of the traded items*[27]. Based on these simple but powerful ideas, Barzel and others demonstrate that measurement difficulty and measurement costs have rich ramifications for economic organization.

Moreover, in his effort to disentangle the relation between a series of intertwined notions such as measurement costs, informational costs, enforcement costs, transaction costs, property right, incentive structure etc., and in particular in his enquiry into the cause and consequence of positive measurement costs, Barzel makes clear a few critical linkages between the above few notions. Together with some

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As a general conclusion, Alchian and Demsetz suggest that metering difficulties could be related to informational costs, and "***to each source of informational cost there may be a different type of policing and contractual arrangement.***" To put this more explicitly, to Alchian and Demsetz, every specific contractual arrangement (including what they label as the "firm") is nothing more than a "particular policing device" to economize on a particular source of informational cost. Viewed in this perspective, they confess that what they have been doing in this classical paper is to "seek to identify and explain a particular contractual arrangement induced by the cost of information factors" in the context of team production.
These ideas, were then taken up and further developed in greater detailed by McManus (1975), Barzel (1977; 1982; 1985; 1989; 2001; 2005), Ouchi (1980) etc.

[26] McManus (1975) is the first to systematically explore the measurement issue.

[27] "Virtually no commodity offered for sale is free from the cost of measuring its attributes; the problem addressed here is pervasive" (Barzel, 1982: p. 28).

other researchers in the same field, Barzel has contributed a very general view of transaction costs. Such a view has been adopted[28] and incorporated into a very general definition[29] of transaction costs (Allen, 1991, 1999) which seems to unify different approaches within transaction cost economics.

The essence of Barzel's insights can be summarized as:

(1) The problem of measurement is ultimately a problem of information. According to Barzel, "measurement is the quantification of information" (Barzel, 1982: p. 28, footnote 3) and *costliness of product information*[30] is the source of measurement costs (Barzel, 1982, 1985). It is the case because "had information been costless, the level of desired attribute and defects of the traded item could be effortlessly identified at the time of exchange" (Barzel, 1982, p.27), the necessity of measurement would thus be totally eliminated.

(2) Barzel goes on to argue that the implication of costless product information is even more far reaching. In a more general sense, transaction costs "acquire their special character from the cost of product information" (Barzel, 1985, p.5) and "costly product information is the central problem of transacting, leading to all other transacting problems" in that if product information were costless, "it seems that a whole array of other costs of transacting would then disappear" (Barzel, 1985: p. 6). The critical link between costly information and positive transaction costs, as explained by Barzel, lies in property rights. If product information is costless, it would at the same time imply that "property rights are complete and costlessly enforced" (Barzel, 1985: p. 7), while in such a world of perfect property rights, transaction costs must be zero (Barzel, 1977)[31]. Barzel later reformulates his argument as "costliness of product information is a necessary condition for the existence of positive transaction costs"[32] (2001, p. 15-

[28] Allen (1999) recognizes the influence from Barzel in forming his "property right definition of transaction costs".

[29] See note 1 at the end of this chapter.

[30] Product information is defined by Barzel (1982, p.28) as "information on the levels of the attributes per unit of the commodity and on the actual amount contained in the nominal quantity."

[31] This is one of the basic points made in Barzel (1977). An articulation of the same point could be found in Cheung (1992, p. 54), who states:
"the dual specifications of clearly delimited rights and zero transaction costs are redundant. If transaction costs are truly zero, the delineation of rights can be ignored."
Douglas Allen (1999, p.899) makes it even more clear by stating that:
"To say that a situation has zero transaction costs is to say that property rights are complete"

[32] To make this point more clearly, we could express the above few relationships as the following few logical judgements:
costless information $\Rightarrow$ perfect property rights $\Leftrightarrow$ zero transaction costs;
thus, costless information $\Rightarrow$ zero transaction costs
since a statement and its contrapositive are equivalent, we have,
positive transaction cost $\Rightarrow$ positive information cost

16).

(3) Given the costliness of product information, if one further assumes that the cost of the accuracy of measurement is increasing, it can be inferred that attaining perfectly accurate measurements would be prohibitively costly so that measurement errors are unavoidable. As a consequence of errors in measurement, property rights are not well defined (Barzel, 1982). Accordingly, in such a world of incomplete property rights, individuals are expected to spend resources to protect and capture the benefit from these rights, therefore arise the transaction costs (Cheung 1974; Barzel, 1982; 1985; 2001).

Based on the above ideas, Barzel (2001, 2005) contends that measurement costs can serve as an operational concept and a unifying element for understanding economic organization in general and the boundary determination of the firm in particular.

Barzel argues, given that perfect accuracy of measurement is prohibitively costly and that measurement errors are unavoidable, economic property rights are in fact never well-defined. Individuals spend resources to capture, maintain and protect these rights, mainly by economizing on the measurement costs, or more generally, through choosing the right measurement variable which in turns leads to the economizing of transaction costs (Barzel, 1982). Barzel notes that the choices of how, when and what to measure may significantly alter transactors' behaviour, and he contends that such choices should be understood in terms of the choice of ***incentive structures***. Generalizing Alchian & Demsetz's similar argument that firm and market refer to quite different methods of measurement, Barzel asserts that in market transactions the *attributes of the product* that buyers desire are measured directly, while within the firm, the *productive effort of labour* that the employers desire is measured instead. Therefore, the incentive structures of these two organization forms differ, and this might explain why firms have a comparative advantage in organizing some productive activities. Relatedly, Barzel (2001, 2005) argues that since transactions have multiple attributes, and it is too costly to measure them all, optimizing implies choosing only some of the attributes to be measured, while the choice of what to be measured and what not to would amount to the choice of distinct incentive structures,

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thus, positive information cost (costly information) is a necessary condition for positive transaction cost.

It is also worth noting that information costs are not always transaction costs (Allen, 1999). One version of Steven Cheung's definition of transaction costs might be helpful to illuminate this point. According to Cheung (1998), "'Transaction costs' must be defined to be all the costs which do not exist in a Robinson Crusoe economy". Observed from this perspective, it might be obvious that Crusoe does not have any transaction costs problem before Friday turns up, but he still has to face up to the information problem. In this example of single-person economy, positive information cost and zero transaction cost coexist.

such choice—as he demonstrates[33]—would result in very different efficiency results. In this view, measurement concerns can provide critical clues for understanding different organizational forms and contractual designs.

2.2.2 Oliver Williamson on Transaction Costs

Arguably, Transaction Cost Economics is most widely known through Oliver E. Williamson's series of influential contributions (1971, 1975, 1985a, 1996c). Given its sweeping influence or even dominance in the theory of the firm and organizational economics, a detailed review of the Williamson’s theory is warranted. However, this section is merely intended as a first step and will focus narrowly on Williamson’s understanding of transaction costs.

Among Williamson’s work, the section titled “transaction cost” in the first chapter of his 1985 book would be the most representative text in which Williamson explains in detail his understanding of transaction costs. The following three points can be summarized as distinctive of Williamson’s understanding of transaction costs.

A. Overview

Concurring with Arrow’s definition, Williamson writes that:

> “Kenneth Arrow has defined transaction costs as the “costs of running the economic system” (1969, p. 48). Such costs are to be distinguished from production costs, which is the cost category with which neoclassical analysis has been preoccupied. Transaction costs are the economic equivalent of friction in physical systems.” (Williamson 1985, pp. 18-19)

Williamson admits that sometimes it might be desirable to assume away the frictions when formulating theories. He argues, however, to have a correct appreciation of

[33] One interesting example could be found in Barzel (2001, footnote 4). In this shipment of truckloads example, payment/measurement could either be made on a lump sum basis (per shipment), or by hour, but they would induce very different behaviour on the part of the trucker. Paying a lump sum per shipping may induce timely delivery, which might be ideal for shipment of bricks. Nevertheless, if the truckload is instead china, timely delivery is bound to result in heavy breakage. The shipper could, however, improve on this result by switching to paying by hour. Being paid by hour (and monitored not to charge for time in the bar), the trucker tends to be less inclined to rush, thus less damage could be expected.
Barzel tries to use this example to illustrate the differences in incentive structure between the firm and the market. However, it seems to me that this example would be more comfortably understood in light of the choice of different contractual designs, rather than the make or buy decision. As far as the trucking service is concerned, both market and firm could, in principle, either pay in lump sum, or pay by hour.

how the real-world economic system works, such frictions should be taken expressly into account. In particular, without express provision for transaction costs being made, *we would lose most of the clues to the understanding of the choice of organizations modes*, since most of the non-standard modes of organization, in his view, operate to serve the purpose of transaction costs economizing. The ensuing problem is—how to make express provision for transaction costs? Although Williamson does not offer a comprehensive definition, he describes the essence of transaction costs analysis as "an examination of the *comparative costs of planning, adapting, and monitoring task completion under alternative governance structures* (Williamson 1985, p. 2, italics in the original). To operationalize such comparative analysis of transaction costs, he further suggests that "transaction costs of *ex ante* and *ex post* types are usefully distinguished" (Williamson, 1985, p. 20).

B. Ex ante/ex post distinction of transaction costs

Convinced by John R. Commons' (1932) argument for the unit of analysis (1932), and following the tradition of transaction cost literature, Williamson takes transaction as the basic unit of analysis and he asserts that the problem of economic organization should be posed as a problem of contracting (Williamson, 1985, p. 20.) According to Williamson, "a transaction occurs when a good or service is transferred across a technologically separable interface" (Williamson 1985, p. 1), while each transaction can be organized by a variety of governance structures, with which explicit or implicit contract and different supporting apparatus are associated. In this contractual lens, the *ex ante* and *ex post* types of transaction costs are particularly relevant.

According to Williamson, the *ex ante* transaction costs "are the costs of drafting, negotiating, and safeguarding an agreement" (Williamson, 1985, p. 20), which can be understood as the costs of actions and tasks involved in establishing a contract (Alchian & Woodward, 1988).

For Williamson, this category of transaction costs is not of primary concern. Williamson notes that most of the previous studies seem to have *judicial efficacy*[34] as their background assumption which is evident of the influence of *legal centralism*[35], and he observes that neither legal centralism nor judicial efficacy is consistent with the reality. Quoting Galanter (1981), Williamson points to the fact that most disputes,

[34] Williamson (1985, p. 20) finely summarizes this assumption as "efficacious rules of law regarding contract disputes are in place and are applied by the courts in an informed, sophisticated and low-cost way".

[35] Legal centralism maintains that remedies to contractual disputes are basically ruled and dispensed in and effortless way by an external omniscient judicial body, often operating under the auspice of the state (Galanter, 1981).

including those eligible for being brought before a court, are resolved through private ordering rather than public ordering. This is the case since in many instances, the parties to a dispute can work out more satisfactory solutions than can professionals constrained to apply general rules on the basis of limited knowledge of the dispute. On a more abstract level, Williamson argues that the combination of contractual incompleteness (by reason of bounded rationality) with strategic misrepresentation (by reason of opportunism) makes it impossible for an outside arbiter (the courts) to establish accurately what has transpired after the fact; thus common knowledge between the contractual parties, even if there is any, does not preclude costly maladapation and *ex post* bargaining, the *ex post* costs of contract thus unavoidably intrude (Williamson, 1971, pp. 115-117; 1975, pp. 31-37; 1985a, p.21).

According to Williamson, the *ex post* costs of contracting include:

> "(1) the maladaption costs incurred when transactions drift out of alignment in relation to what Masahiko Aoki refers to as the "shifting contract curve" (1983), (2) the haggling costs incurred if bilateral efforts are made to correct *ex post* misalignments, (3) The setup and running costs associated with the governance structures (often not the courts) to which disputes are referred, and (4) the bonding costs of effecting secure commitments." (Williamson, 1985a, p. 21)

Williamson emphasizes in particular that most of the contractual hazards arise in the post contractual stage. Though appropriate *ex ante* incentive alignment could help to mitigate some of these hazards, in a world of incomplete contracting, not all of relevant contracting actions can be packed into *ex ante* incentive alignment; rather, they would inevitably spill over to *ex post* governance (Williamson, 1993). Moreover, contrary to the belief of legal centralism (which roughly implies costless or at least inexpensive *ex post* bargaining), the adaptive efficacy of alternative modes of organization (market, hybrid, hierarchy, etc.) in *ex post* governance respects differ systematically, thus, the choice of governance structures that have good *ex post* adaptive properties is of higher priority (Williamson, 1985a, 2003a, 2005d). Summing up, to Williamson, "cost-effective mitigation of contractual hazards through the mechanism of *ex post* governance is what TCE is all about" (Williamson, 2003c: p. 14).

C. The role of asset specificity

One of Williamson's genuine contributions is to identify the few critical dimensions of transactional attributes (Williamson, 1979) by which transaction costs in various governance structures line up with regularity, thus a comparative analysis of transaction costs across various discrete structural alternatives can be undertaken systematically. More specifically, such a comparative analysis is implemented through the "discriminating alignment hypothesis", to wit: "transactions, which differ in their attributes, align with governance structures, which differ in their cost and competence, in a discriminating (mainly transaction cost economizing) way" (Williamson, 1991: p.277). According to Williamson, transactions have three "critical dimensions": *uncertainty*, *frequency*, and *asset specificity*[36] (Williamson, 1979: p. 239). But the "most critical dimension for describing transactions is the condition of asset specificity" (Williamson, 1985a: p. 30) since the post-contractual maladaption, as in the case of being held-up (B. Klein, Crawford, & Alchian, 1978), would be most drastic when a highly specific asset is involved. Indeed, asset specificity has been assigned with such a central role in Williamson's theory that it tends to crowd out all others in the explanatory pantheon. (Langlois & Foss, 1997: p. 8)

Summing up, it seems that Williamson's understanding of transaction costs has been based on and prompted in part by the insights accumulated through the scholarly work before mid-1970s'—work that aims at pinning down the slippery term as I just reviewed in detail.

Such understanding is synthetic in nature and has incorporated some of the above-mentioned basic consensus[37] regarding how transactions costs should be understood and analyzed. On the other hand, being widely recognized as one of the most prominent contributors to the Transactions Costs Economics, Oliver Williamson's understanding has added much operationalizable content to the transaction costs reasoning. Williamson (1971) is the first to note the role sunk costs can play in causing post-contractual strategic bargaining problems and incentives for vertical integration in a world of *bounded rationality* and *opportunism*. This idea, later refined as *asset specificity*, has been so attached to the name of Williamson that—as has been pointed out by Allen (1999)—for many, transaction costs means little else. Objectively speaking, it might be unfair to blame Williamson for such an unbalanced and biased view, but it is still not exaggerated to observe that he has left on the whole literature a strong imprint of his personal interpretations .

[36] Originally known as "transaction-specific investments" or "idiosyncratic investments" (Williamson, 1979).
[37] See Williamson (1979, p. 234) for a statement of such consensus as he perceived it at that time.

Theses points might not be so evident in this section, but as the whole Williamson's story fully unfolds in the following chapter, they would become even clearer.

2.3 Conclusions

This chapter is devoted to a review of the evolution of the conception of transaction costs in transaction cost economics literature. It consists of two parts.

In part one, we review the evolution of the concept of transaction costs in the early transaction cost literature (to the end of 1970s). By identifying a few critical papers—i.e., Coase (1937), Coase (1960), Arrow (1969), Cheung (1968, 1969a, 1969b, 1970) and Dahlman (1979)—that contribute to a systematic understanding of the notion of transaction costs, we demonstrate how some consensus regarding the connotations and nature of "transaction costs" emerges over time. Fueled in part by these contributions, at least by the end of 1970s, a certain consensus on the connotations and nature of "transaction costs" emerge, viewing transaction costs (1) as the costs of running institutions, which universally exist in any mode of resource allocation; (2) through the lens of contract, around different phases of which transaction costs evolve; (3) with a connection to property rights, and; (4) as resulting from "lack of information".

In part two, we show that once the consensus emerged, the expanding branching of distinct approaches within transaction cost economics further advances our understanding of transaction costs in some particular aspects. Specifically, we review on a selective basis some of the most representative literature in four different approaches within transaction costs economics—i.e., the property rights approach, the agency approach, the measurement approach and Oliver Williamson's governance approach. With a particular emphasis on their respective contributions to the understanding of "transaction costs" and the corresponding boundary implications, we show that each of the approaches has quite different emphases when applying the transaction cost reasoning to explain the existence, boundary determination or internal organization of the firm. In doing so, the once slippery concept has been further clarified, refined and operationalized and our understanding is enriched.

In particular, we show that Alchian and Demsetz (1972) is a truly seminal contribution. In the context of "team production", this paper simultaneously addresses the triple issues of property rights and incentive alignment, agency problem and metering problem which corresponds exactly to themes of the property rights approach, the agency approach and the measurement approach. In fact, the further branching of the three approaches within the transaction cost economics, to a large extent, is inspired by the publication of this paper.

Moreover, we show that Williamson's understanding of transaction costs has been based on and prompted in part by the scholarly insights accumulated before mid-1970s'. At the same time, we also note that asset specificity has been assigned with such a central role in Williamson's theory that it tends to crowd out all others in the explanatory pantheon.

Note

[1] According to Allen (1991, p3),

> "Transaction costs are the resources used to establish and maintain property rights. They include the resources used to protect and capture (appropriate without permission) property rights, plus any deadweight costs that result from potential or real protecting and capturing."

Elaborating on definition, Allen (1991, p4) explains that transaction costs, so defined, arise in three situations: (1) "coerced exchanges— better known as theft"; (2) expenditures designed to deter theft ("locks, guard dogs, and hand guns") or commit theft ("picks, mace, and more hand guns"), as well as "efforts to prevent or take advantage of appropriable rents"; and (3) "effort to capture the wealth of others and to prevent one's own wealth from being taken," which is present in every voluntary exchange. In a later paper (Allen, 1999, p.899), Allen further comments that "any direct costs, as well as any concomitant inefficiency in production or misallocation that resulted from them", should be included as transaction costs.

Following the tradition started by Alchian (1965) in property right literature, Allen stresses in particular that *economic rights* rather than *legal rights* is at the heart of property rights. More specifically, property rights are "the ability to freely exercise a choice over a good or service" (Allen, 1999, p.898). These rights are not just under law, but in reality. They are enhanced by the law, but they are ultimately use rights regardless of the law.

Allen admits that, apart from Alchian, Cheung and Barzel's work have a major influence on his version of property rights definition of transaction costs.

Allen argues(1999, p. 899), the "property rights definition of transaction costs respects no boundaries between firms, markets, households, or any other theoretical constructs. When property rights are protected and maintained in any context, transaction costs exist".

In terms of its generality, Allen's definition is rather satisfactory in that it is compatible with all major branches of transaction costs literature. Its consistency with property rights literature and measurement literature might be apparent. A careful examination of Jensen and Meckling's definition of "agency costs", would also reveal that even their definition deals with a relatively narrower subject, the three categories that they have included in "agency costs"—the monitoring costs of principal, the bonding costs of agent and residual losses—fall squarely under Allen's definition as well. This conclusion would be most apparent if each of the categories is examined against what Allen has listed as the three situations in which transaction costs arise. Finally, Williamson's understanding of the relationship between transaction costs is also fully compatible with the definition presented above. As might be evident later, even that the Williamson's understanding (1975; 1985; 1996) is featured with a strong, if not exclusive, emphasis on the part of transaction costs resulting from asset specificity and associated hold-up problem, such costs, as he illustrates, vary systematically across different "governance mechanisms" which in essence could be understood as distinct sets of distribution of property rights with different incentive features.

Chapter 3: Transaction Cost Economics and Williamson's Theory of the Firm

In the previous chapter, we review in great detail the evolution of the concept of "transaction cost" in the transaction cost literature. We note that for quite a long time after "*The Nature of the Firm*" article was published (Coase, 1937), it is "much cited and little used" (Coase, 1972: p. 63). As Williamson (1975, p. 3) observed, "transaction costs are appropriately made the centerpiece of the analysis but these are not operationalized in a fashion which permits one to assess the efficacy of completing transactions as between firms and markets in a systematic way". In fact, Williamson's overall contributions, in his own perception (Williamson, 2010a, 2010b) and as recognized by the Nobel Prize Committee, is to operationalize the basic Coasian ideas by working out a positive research agenda enabling a systematic analysis of transaction costs in a comparative institutional way.

Throughout his career-long commitment to the development of Transaction Costs Economics (TCE), Williamson has built an impressive theory which has become one of the leading perspectives in the study of economic organization (in particular, the theory of the firm). In recent years, Williamson has elaborated on numerous occasions (Williamson, 1998b, 2000, 2002a, 2002b, 2003b, 2005a, 2005c, 2010a, 2010b) the basics of his approach. For an overview of Williamson's transaction cost economics, it is appropriate to begin this chapter by summarizing these basic precepts. This will help us to position Williamson's approach against other parallel lines of reasoning in the theoretical landscape, so that an identification of its contributions, strengths and weaknesses would be facilitated. In the section that follows, we discuss in more detail the basic framework of Williamson's theory to the boundary determination of the firm. In section three, we present first the basic insights of the GHM model, which is often described as the formalization of Williamson's theory. We then compare the differences between these two approaches and conclude that the GHM should not be understood as a formalization of Williamson's theory as they offer fundamentally different insights.

3.1 Basics of Williamson's Transaction Cost Economics

As a theoretical paradigm in Kuhn's sense (1962), the basics of the (Williamsonian) transaction cost approach to the theory of the firm can be summarized in the following few aspects.

3.1.1 TCE and NIE

Transaction costs approach to the theory of the firm, or more generally, transaction costs economics (TCE), is part of the intellectual movement known as "New Institutional Economics" (hereafter NIE)[1] (Williamson, 1985b: p. 16). This body of thinking, taking shape in the 1970s, is based on two basic propositions: institutions matter, and institutions are susceptible to analysis (Matthews, 1986: p.903). In fact, the term "New Institutional Economics" was first coined by Williamson (1975: p.1) and Williamson's (governance) approach to the theory of the economic organization has been the best-known—and probably the most fruitful—stream of contributions within NIE.

3.1.2 Transaction as the Basic Unit of Analysis and Economics as the Science of Contract

One of the research traditions that links NIE with its predecessors has been taking transaction—which includes an exchange as well as a contractual dimension (Alchian & Woodward, 1988: p. 66)—as the basic unit of analysis. Back in 1932, John Common urged that the transaction should be made the basic unit of analysis. According to him, "the ultimate unit of activity… must contain in itself the three principles of conflict, mutuality, and order. This unit is a transaction" (Commons, 1932: p. 4). This view has been echoed by his modern successors. Ronald Coase, in his 1937 article, first introduced the notion of transaction cost and adopted a lens of contract in his analysis of the boundary determination of the firm. James Buchanan (1975: p. 225), another Noble Prize laureate, argued explicitly and more radically that economics, which has been developed throughout the twentieth century as a science of choice, had gone "wrong" in its preoccupation with the optimization apparatus associated therewith. According to Buchanan, "mutuality of advantage from voluntary exchange…[is] the most fundamental of all of understanding in economics" (Buchanan, 2001: p. 29), therefore, parallel development in economics as a science of contract is very much needed (1964a, 1964b, 1975). Partially concurring with Buchanan's view, Williamson (2002b: p. 172) suggests that the science of choice is not the only lens for studying complex economic phenomena, nor is it always the most instructive lens. Transaction cost economics employs the lens of contract, rather than the orthodox lens of choice; it not only subscribes to John R. Commons' view by taking the transaction as the basic unit of analysis, but also views governance structure of contractual relation as "the means by which to

[1] See note 1 at the end of this chapter.

infuse ***order***, thereby to mitigate ***conflict*** and realize ***mutual*** gains" (Williamson, 2003b: p. 921, emphasis original).

3.1.3 Transaction Cost Economizing and Comparative Contracting

According to Williamson (1981; p. 552), "a transaction occurs when a good or service is transferred across a technologically separable interface". Just as there are frictions across the interfaces in mechanical systems, parties to the exchange do not always operate harmoniously, misunderstandings and conflicts are frequent, which leads to delays, breakdowns and other malfunctions. The economic counterpart of friction in physical systems is *transaction costs*. Moreover, when a particular transaction is to be effected, it can be organized by a series of contractual alternatives (governance structures), but at different transaction costs. The choice of contractual form is therefore mainly[2] based on transaction cost economizing considerations (Williamson, 1979, p. 245) . By taking transaction as the unit of analysis and adopting the lens of contract, transaction cost analysis supplants the usual preoccupation with technology and steady-state production expenses with "an examination of the comparative costs of planning, adapting, and monitoring task completion under alternative governance structures" (Williamson, 1981; p. 552-553). As against orthodoxy, issues of organization, rather than technology, become conspicuous in this lens (Williamson, 2003b: p.921); and the problem of economic organization is posed as a micro-analytic problem of *comparative contracting* (Williamson, 2002b, 2003b).

3.1.4 Key Moves of Operationalization

The comparative contractual approach to the issue of economic organization in general and to the theory of the firm in particular, is implemented through a series of key operationalizing moves (Williamson, 1979, 1985, 1991). These moves include: (a) identifying the behavioural assumptions that are necessary to produce non-trivial problems of economic organization; (b) dimensionalizing the few critical attributes that are responsible for differential transaction costs under alternative modes of governance; (c) naming and explaining the critical attributes with respect to which

[2] Transaction-cost economics concentrates on transaction cost economizing (Williamson, 1985: p. 22-23) and takes it as the "main case" (Williamson, 1989: p. 137-138), but it also maintains that this is not the only case (Williamson, 1991: p. 286). More explicitly, Williamson has asserted that the object of economic organization "is not to economize on transaction costs but to economize in both transaction and neoclassical production cost respects" (Williamson, 1985: p. 61), i.e., economizing takes place with reference to "the sum of production and transaction costs" (Williamson, 1979: p. 245). That being stated, how different modes of organization (governance structures) are chosen to economize in the production cost respect is seldom, if ever, examined seriously in the transactions costs literature.

governance structures differ and then describing them as discrete structural alternatives, and; (d) working out the logic of efficient alignment.

3.1.5 Behavioural Assumptions

As stated by Simon (1985: p. 303), "nothing is more fundamental in setting our research agenda and informing our research method than our view of the nature of the human beings whose behaviour we are studying". In the contractual world of transaction cost economics, two behavioural assumptions regarding the human actors have been identified as crucial for setting up the analysis (Williamson, 1975, 1985b)—namely, bounded rationality and opportunism. By these two assumptions, transaction costs economics distinguishes itself from the neoclassical orthodoxy in which the human actors are conceptualized as "rational utility maximizers" (Coase, 1984: p. 231), thus informing its analysis with a fresh focus and more realistic substance.

Specifically, bounded rationality (intended rational, but only limitedly so) is the cognitive assumption to which Simon (1957: p. xxiv) first refers, by which he tries to capture the parts of human behaviour that are intendedly rational but nevertheless constrained by their cognitive limitations. Viewed from the lens of contract[3], the main economic implications of bounded rationality are that ***all complex contracts are unavoidably incomplete***, and that the need for ***adaptive, sequential decision-making*** to unanticipated disturbances arising from gaps, errors, omissions and divergences in understanding in/to the original contact should be appreciated (Williamson, 1975, 1985b). The second assumption is that of opportunism, which is defined as "self-interest seeking with guile" (Williamson, 1975: p. 6), a notion that harks back to Williamson's early work on the managerial theory of the firm (Williamson, 1964). Upon making provision for opportunism, the issue of "strategic behaviour" (Schelling, 1960) that had been ignored by orthodoxy occupies a central position (Williamson, 2002a). Taking together these two assumptions, in the contractual world of transaction costs economics, human actors are not only confronted with the need to adapt to unforeseen contingencies (by reason of bounded rationality), but are susceptible to the jeopardy of strategic behaviour (by reason of opportunism). The hazards of costly contractual breakdown therefore loom large. To be sure, these hazards might not pose a serious problem if perfect judicial efficacy can be assured. However, when bounded rationality, opportunism and idiosyncratic knowledge are joined (Williamson, 1975: pp. 31-33), the problem of non-verifiability

[3] The chief ramification of bounded rationality in the lens of choice is that maximizing should give way to "satisficing" (Simon, 1957 p. 204).

to the third-party enforcer imposes. Third-party dispute resolution is therefore costly and can not always be relied on. Overall, the upshot is that private ordering effort to craft supportive governance structures, thereby to facilitate more harmonious adaptive sequential decision-making (economize on bounded rationality) and to mitigate contractual hazards (opportunistic behaviours) during the contractual implementation interval, has merit (Williamson, 2002b).

3.1.6 Dimensionalizing Transactions

The magnitude of the contractual hazards varies systematically with the attributes of transactions. Three key dimensions of transaction attributes have been identified as having important governance ramifications by which transaction costs in various governance structures line up with regularity (Williamson, 1979). These three dimensions are: asset specificity (i.e., the degree to which durable transaction-specific investments are incurred, which takes a variety of forms—physical, human, site, dedicated, brand name, temporal—and is a measure of bilateral dependency), uncertainty (which is a measure of potential disturbances to which transactions are subject and maladaptations accrue) and the frequency with which transactions recur (which bears both on the efficacy of reputation effects in the market and the incentive to incur the cost of specialized internal governance). As asserted earlier and made even clearer later, in Williamson's view, the most critical dimension is that of asset specificity since the governance ramifications of the other two dimensions can not be fully and independently appreciated until joined with asset specificity (Williamson, 1979: p. 239).

3.1.7 Dimensionalizing Governance Structures

Transactions can be organized by a variety of contractual alternatives. The choice of organization forms, in Williamson's parlance, is the choice of "governance structures", by which term is meant "the organizational frameworks within which the integrity of a contractual relation is decided" (Williamson, 1985b: p. 41). Transaction cost economics holds that the few generic modes of governance—market, hybrid, hierarchy etc.—differ from each other by a syndrome of internally consistent attributes to which different adaptive strengths and weaknesses accrue. These attributes, as identified by Williamson (1991), are incentive intensity, administrative controls, and contract law regime. Such a conception has several ramifications. Above all, in this picture, governance structures are described as what Simon called "small number of discrete institutional alternatives" (H. A. Simon, 1978: p.6). Consequently, the choice of governance structures turns out to be an exercise of "discrete structural analysis" in which the focus has been placed on first-order economizing rather than second-order optimization (Williamson, 1991). Therefore, much of "elaborate mathematical apparatus or marginal calculation" (H. A. Simon, 1978: p.6) tends to be less relevant. In this view, the firm is no longer viewed as a stand-alone entity—a black box through which the inputs are transformed into outputs according to exogenous given technology. Rather, it is conceived as a comparative contractual construction—one of the few generic modes of governance always to be compared with other alternatives in light of transaction costs economizing purpose. Moreover, under different modes of governance, the combinations of the few critical attributes are such that they are *complementary*, *internally-consistent* configurations (Williamson, 1991). Each mode of governance differs in kind rather than in degree; therefore, it is impossible for a governance mode to replicate a particular attribute (e.g. incentive) of another governance mode while maintaining other attributes unchanged. This would explain the *impossibility of combining replication with selective intervention* (Williamson, 1985b: pp. 132-144).

3.1.8 Discriminating Alignment Hypothesis, the Refutable Predictions and the Empirical Success Story

Taking the lesson of its OIE (old institutional economics) predecessors' failure to advance a positive research agenda (Williamson, 1998a), and also trying to redress the tautological reputation (Coase, 1984; Matthews, 1986; Stigler, 1983; Williamson, 1998b) of the Coasian theory, the Williamsonian transaction cost economics subscribes to the proposition that "the purpose of science in general is not prediction, but knowledge for its own sake", yet that prediction is "the touchstone of scientific knowledge" (Georgescu-Roegen, 1971: p. 37). Specifically, a strong emphasis has been placed on the going beyond *ex post* rationalization to derive refutable predictions, and submit them to data (Williamson, 1998b: p. 36; 2003b: p. 936).

Transaction cost economics owes much of its predictive content to the "discriminating alignment hypothesis" (Williamson, 1991) which holds that transactions, which differ in their attributes, are aligned with governance structures, which differ in their costs and competencies to implement autonomous and coordinated adaptations, in a discriminating (mainly transaction cost economizing) way. In Williamson's view (2003b, 2005a), the basic regularity revealed by implementing the logic of efficient alignment can be described as follows:

Asset specificity in conjunction with uncertainty (disturbances) is where the main predictive action resides. As asset specificity—which gives rise to bilateral dependency—increases, and as disturbances—which result from uncertainty and push the parties off of the contract curve—become more consequential, the door for opportunistic behaviour opens and the needs for coordinated adaptations increase. The efficient governance response to building up contractual hazards and added needs for coordinated adaptations is to move transactions, as a first step, from spot markets (neoclassical ideal) to hybrid contracting (in which private-ordering credible commitments have been crafted) and, if unmet needs for added coordination persist, to hierarchies (unified ownership). Generic transactions are thus ideally managed by the spot market—which works out of *high-powered incentives*, *little administrative control*, and *a legal-rules contract-law regime*, and is well suited to implement autonomous adaptations. Complex transactions are managed by the hierarchy—which on the other hand leverages *low-powered incentives*, *considerable administrative controls*, and *internal dispute settlements* to which the external courts are deferential, and is well suited to effect coordinated adaptations. Hybrid modes of governance are employed for those transactions that are in between. This pattern applies, in the first place, to the paradigmatic problem of make-or-buy decision and the boundary determination of the firm (P. Klein, 2005; Macher & Richman, 2008; Shelanski & Klein, 1995), but it can be extended to include other issues that arise as (or can be reconceptualised as) a contracting problem—for example, corporate finance (Williamson, 1988a), labor organization (Williamson, 1985b: Chapter 10; Williamson, Wachter, & Harris, 1975), and regulation (Paul L. Joskow, 1991, 2002). In Williamsons' perception (Williamson, 1996a, 1999b, 2010b), "transaction cost economics is an empirical success story" (1996a: p.55)[4], not just in its insistent emphasis on refutable implications and empirical testing; more importantly, the predictions that accrue upon implementing the overarching logic of efficient alignment have stood up to numerous empirical tests in which the data have been shown to be broadly corroborative (Geyskens, Steenkamp, & Kumar, 2006; P. Klein, 2005; Lajili, Madunic, & Mahoney, 2007; Macher & Richman, 2008; Masten, 1999; Masten & Saussier, 2002; Shelanski & Klein, 1995). The view has been supported by some scholars (Geyskens, Steenkamp, & Kumar, 2006b; Paul L. Joskow, 1991; Whinston, 2001). For example, Paul Joskow concurred that "this empirical work is in

[4] However, recent surveys (Carter & Hodgson, 2006; David & Han, 2004; Plunket & Stephane, 2003; Ruzzier, 2009) suggest that relevant empirical evidence is more mixed than previously claimed. Specifically, it has been shown that there are deficiencies in many of the existing tests. In particular, many studies do not pay sufficient attention to econometrics issues such as endogeneity (Hamilton and Nickerson, 2003; Mayer and Nickerson, 2005; Shaver, 1998), and there is less evidence that a given choice predicted by the TCE theory really outperforms other feasible alternatives. Apart from this, there are problems with the operationalization and measurement of many of its constructs (e.g. asset specificity) (Mayer, 2009). Given these, one might wonder to what extent, TCE is really an empirical success story.

much better shape than much of the empirical work in industrial organization generally"(Paul L. Joskow, 1991: p. 81).

3.1.9 Remediableness as Efficiency Criterion and the Public-Policy Ramifications

Given that transaction cost economics was led by the research stream that explored the causes of market failures (in particular, externality problems and information problems) and the possibilities of welfare improvements (Alchian, 1965; Arrow, 1963, 1969, 1971, 1974; Coase, 1960; Demsetz, 1969); and that the Williamsonian transaction costs economics was in part stimulated[5] by the evolving crisis in antitrust enforcement and regulation during the 1960s (Paul L. Joskow, 1991; Williamson, 2005a), it is little wonder that, compared with other parallel contributions to economic organization, TCE is more concerned with public policy ramifications. In addition, as Dixit observed (Dixit, 1996: p. 9), by furnishing the analysis with the lens of contract/governance, and by developing richer paradigms and models based on the concepts of various kinds of transaction costs, transaction cost economics brings to an end "the era of black-box applied welfare economics" in public-policy analysis. Indeed, it could even be argued that the changes of climate in regulation (antitrust in particular) are attributable, to a certain extent[6], to the wide acceptance of the transaction cost reasoning in the economics profession, by which the conventional wisdom regarding the efficiency implications of various business practices has ever since been reversed (N. J. Foss & Klein, 2008a) .

[5] It is worth noting that Williamson's experience as Special Economic Assistant to the head of the Antitrust Division of the U.S. Department of Justice during 1966–1967 has had an influence in shaping his research interest (Williamson, 2005a). His 1975 seminal book *Markets and Hierarchies*, was indeed subtitled with "Analysis and Antitrust Implications" and this was seemingly among the first attempts, besides that of Coase (1972), to take issue with the "inhospitality tradition" in antitrust.

[6] According to Joskow (1991), most of the impetus of this transformation should be more appropriately accredited to the "Chicago School" of antitrust economics (Bork, 1978; Peltzman, 1969; Posner, 1976), which, long before transaction cost economics came into full bloom, raised criticism of traditional hostility of the antitrust laws to vertical integration and non-standard vertical relationships, and which, more importantly, had a more direct and obvious influence in shaping the views of the antitrust policy-makers. Joskow (1991) also points out that the arguments of these two branches of literature are largely complementary. Specifically, TCE argues that non-standard business practices can and do serve transaction-costs-economizing purposes and are thus, more often than not, efficiency-enhancing; while Chicago-school scholars maintain that such practices are neither a consequence nor a cause of market power, therefore, they do not necessarily result in reduced competition and the accompanied efficiency-loss. As has been identified by Meese (1997), the Chicago position on vertical restraints relies largely, though less explicitly, on the background assumption of costly transaction. Moreover, as indicated by Joskow (1991), if not for the work of transaction cost economics which demonstrated that previously suspect vertical arrangements can and often do serve cost-reducing rather than anticompetitive motivations, it is hard to believe that the Chicago critique of antitrust policies would have enjoyed as much influence.

As stated earlier, all variants of transaction cost approach to economic organization (Williamsonian, property right, agency, measurement, etc.) share the same propensity of seeking efficiency explanations for non-standard contracts, but it takes decades for an articulated criterion of efficiency to take shape in this literature. Back in the 1960s, Coase (1964) and Demsetz (1969) have criticised the neoclassical[7] criteria for evaluating the efficiencies of alternative modes of economic organization as being asymmetric. As trenchantly pointed out by Coase (1964: p. 195), "in the literature ... we find a category 'market failure' but no category 'government failure'". Relatedly, at that time, there was a habitual propensity in the regulatory arena to derive public policy implications by comparing *actual* market outcomes with *the hypothetical ideal*. As actual markets could never do better than the hypothetical ideal, market failure was always established and held to be a widespread condition. Government—which on the contrary was assumed to be an "omniscient, omnipotent, benevolent" (Dixit, 1996: p. 8) actor who could reliably administer efficacious remedies at virtually no cost—was then called upon to intervene. As indicated by Coase, although such practices might in some special cases be very informative in providing a solution, it would nevertheless, in most cases, give us very misleading ideas about the possibilities of beneficial policy interventions, since in reality, "we are choosing between social arrangements which are all more or less failures", and the "main question" should instead be "how alternative arrangements will actually work in practice" (Coase, 1964: p. 195). To put this plainly, all feasible forms of organization—government included—are flawed, and the choice must be made from the feasible set, hypothetical ideals are operationally irrelevant (Williamson, 1996d, 1996e).

Although the weaknesses of the neoclassical efficiency criterion have been long identified, a constructive new criterion did not emerge in the literature until Williamson (1996d) introduced the remediableness criterion. The remediableness criterion holds that "an outcome for which no feasible superior alternative can be described and implemented with net gains is presumed to be efficient" (Williamson, 1996d: p. 195). When the problem of economic organization is the focus of concern, the above general argument can be readily rewritten as: "an extant mode of organization for which no superior feasible alternative can be described and implemented with expected net gains is presumed to be efficient" (Williamson, 1998b: p. 43). Such a test of efficiency/failure applies not only to the market, but also

[7] In their view, one of the major defects of neoclassical economics is that its analysis often abstracts away the actual working of the economic phenomena, thus lacking empirical basis and realistic substance. Moreover, such analysis could be misleading if employed to derive policy implications. Coase and Demsetz, respectively, has labelled such an unrealistic approach as "blackboard economics" (Coase, 1964: p. 195) and "nirvana economics" (Demsetz, 1969).

to public bureaucracies and indeed to all modes of economic organization (Williamson, 1999a). To be sure, by this criterion, public policy analysts can no longer establish organizational failure of any kind (e.g., market failure, government failure, etc.) simply because extent modes deviate from a hypothetical ideal; rather, they are pressed to display a superior feasible alternative. Moreover, even if a proposed alternative is clearly superior to an extant alternative on a side-by-side comparison, if the implementation of such an alternative involves certain costs (say, setup and/or switching costs), or is confronted with certain obstacles, then such costs/obstacles of implementation should be appropriately included in the net benefit calculus[8]. Thirdly, and relatedly, sometimes the obstacles to implementing a superior alternative manifest themselves either as large-scale coordination problems of taking collective action, or even more explicitly as a problem of political bargaining. In either case, the potential gain may fail to be realized for lack of consensus (or at least, preponderance of consent) to override the *status quo* (Hennipman, 1995; Williamson, 1998b, 1999b). Finally, Williamson emphasized that the presumed efficiency of an extant mode of organization is nevertheless rebuttable (Williamson, 1996d, 1999a). To be more specific, Williamson asserts that if the obstacles to implementing an otherwise superior feasible alternative can be legitimately justified as "unfair"[9] (Williamson, 2010b: p. 684), both in a political and economic sense, then the presumption that an extant mode is efficient if the expected net gain is negative can be rebutted.

Supported by a whole series of operationalizing moves that enable a systematic comparative institutional analysis as described above, the basic logic of transaction cost economics and the remediableness criterion have had an influence on public-policy analysis (Dixit, 1996; Paul L. Joskow, 1991, 2002). Apart from the fact that a more balanced and symmetrical view to the issue of market failure has now enjoyed widespread assent (Stiglitz, 1989), the influence is most evident in the antitrust arena which was once working in the "inhospitality tradition"[10] (Meese, 2004) by which

[8] It should be noted that by the criterion of remediableness, the comparisons are always being made to the advantages of an extant alternative. Even if state A is clearly less efficient to state B in a static side-by-side comparison, if state A is in place and the transition from state A to state B incurs non-trivial setup costs or involves switching costs, state A might still prevail. Such considerations have major ramifications for the issue of path dependency. For a detailed discussion of this point, see Liebowitz & Margolis (1995).

[9] Examples that could be justified as "unfair" include those having unacceptable political origins; those associated with predatory behaviour. Some economic obstacles such as sunk costs incurred by the incumbent might also be classified as "unfair". In this case, a delay in the introduction of a superior feasible alternative might be warranted. For a detailed discussion, see Williamson (1996c, 1999a)

[10] The term was coined by Donald Turner. Acting in his capacity as the head of the Antitrust Division at the Department of Justice during the 1960s, Turner was once quoted (Meese, 2004: p. 47, note 200)

non-standard and unfamiliar contractual and organizational practices were habitually presumed to have anticompetitive purposes and effects (Coase, 1972) . The climate of antitrust today has been changed, and such change owes part[11] of its justification, both theoretically and empirically, to transaction cost reasoning (Paul L. Joskow, 1991, 2002; P. G. Klein, 1999; Rubinfeld, 2001). Specifically, non-standard and unfamiliar contracting practices and organizational structures are more constructively interpreted as private ordering efforts to economize on transaction costs—they can and often do serve efficiency purposes. Thus, although anticompetitive purposes of such practices still remain a concern for the part of regulators, it is regarded as the exception rather than the rule—absent evidence of pre-existing monopoly power, anticompetitive effect is no longer a major consideration (Williamson, 1998a). As confidently observed by Williamson (1996d: p. 201), "remediableness has, in effect, become the operative test criterion for market failure".

3.2 Williamson's Approach to the Boundary Determination of the Firm

In 2009, Oliver Williamson was awarded the Nobel Memorial Prize in Economics jointly with Elinor Ostrom. In the prize announcement, Williamson was cited by the Nobel Prize Committee (2009) for "his analysis of economic governance, especially the boundaries of the firm". Indeed, long before the awarding of the prize, Williamson has been widely acknowledged as the "flagbearer" (N. J. Foss, 2000b) and the chief developer of transaction cost economics (TCE) (Gibbons, 2010; Paul L. Joskow, 2008), with his best-known contribution being the transaction cost theory of vertical integration (Williamson, 1975, 1985b, 1989, 1996b). In this section, I would summarize Williamson approach to the boundary determination of the firm.

On the outset, a few points need to be emphasized. Firstly, given that Oliver Williamson is such a prolific wirier—five books, seven edited volumes, and some more than 170 published papers, all on TCE, mostly related to the boundary issue—what is attempted here is nothing more than a partial review (inevitably incomplete and hopefully not too biased).

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as commenting on the non-standard contractual practices that such practices were approached "hospitably in the common law tradition, but inhospitably in the tradition of antitrust."

[11] According to Klein (1999), the real impacts of TCE on changes in antitrust enforcement are probably still underestimated.

Secondly, as have been noted by many scholars (e.g. Gibbons, 2010; Langlois & Foss, 1999) , there was a tendency[12] in Williamson's work by which he seemed to become increasingly focused on the issue of asset specificity, which perhaps has been one of the central constructs of present-day economics of organization to the extent of crowding out other explanatory variables. On a more general level, it is also worth noting that, in Williamson's early work[13] (before 1978), issues of coordination figured prominently; while in his later work, the theme of coordination faded into the background over time and gave way to a greater preoccupation with incentive issues, of which asset specificity is a prominent case (Langlois, 1998).

Relatedly, it has been argued (Gibbons, 2005) that there are in fact two distinct theories of the firm in Williamson's work—the so-called "rent seeking" theory and "adaptation" theory. In the "rent seeking" theory (Williamson, 1971, 1979, 1985b), integration (with dispute-resolution by fiat) is argued to be more efficient than non-integration because it can reduce socially destructive haggling over "appropriable quasi-rents", often associated with specific investment. Ultimately, a firm can do so because "*ownership can stop haggling that is undertaken via alienable instruments*" (Gibbons, 2005: p. 205, emphasis original). This is the version of theory that has been more fully-developed in Williamson's later work, and that has been followed and discussed in most of the TCE literature. Apart from the better-known rent-seeking theory, Gibbon notes that in Williamson earlier work (1971, 1973, 1975), there is another "adaptation" theory that is independent of the logic of rent seeking and specific investment. Specifically, the "adaptation" theory highlights the role of the authority in facilitating "adaptive, sequential decision-making" (Williamson, 1975: p. 40). In this view, integration is more efficient, because in a world of incomplete contract and uncertainty, neither contracts *ex ante* nor renegotiation *ex post* can induce first-best adaptation after uncertainty is resolved, so that the second-best solution may be to give authority in the hands of a "boss" who then takes decisions after uncertainty is resolved. Gibbons argues, although Williamson's two theories unify in making control (by the authority) the central issue, much of the attention in the ensuing literature tends to focus on the first aspect of his insights that

[12] An interesting indication is provided by Gibbons (2010), who compares the indexes of Williamson (1975) and Williamson (1985) and finds that in Williamson (1975), the word "specific" does not appear all, but the phrase "small-numbers exchange condition" appears 10 times; whereas in Williamson (1985), "small numbers" does not appear, but phrases related to "asset specificity" or "transaction-specific" assets and the like now appear 77 times.

[13] The year of 1978 (on that year Benjamin Klein, Robert G. Grawford, and Armen A, Alchian's "Vertical Integration, Appropriable Rents, and the Competitive contracting Process" was published) is chosen as the dividing year by which Williamson's work is divided into two phases: Williamson's early work and Williamson's later work. In Williamson's early works, (1) explicit reference to asset specificity is hardly seen before the year of 1978; (2) issue of coordination, if not more, is at least as important as issue of incentive.

emphasizes authority as a means of mitigating rent-seeking over appropriable quasi-rents arising from relationship-specific investment, while the second aspect of insights which highlights the role of authority in facilitating relational adaptation in an uncertain world even in the absence of relationship specific investment has gone relatively unremarked.

In short, we believe when evaluating Williamson's overall contributions, one should at least be aware that some of the insights of his early works have gone relatively unremarked, but the significance of these contributions should not be overlooked. That being said, given the space constraints, we would focus on Williamson's later work on the theory of the firm—right or wrong as it might be, this is basically the version of "Williamsonian theory" (Tirole, 1988) that most economists are more familiar with and that most of his followers and successors have received the influences.

In this section that follows, we summarize and review Williamson's later work on the theory of the firm (in particular, the boundary determination of the firm). The review will proceed in the following order. Firstly, we present the basic framework of Williamson's theory of the firm. We then discuss in greater detail a few critical elements in Williamson's theory, namely, the dimensionalization of transactions, the dimensionalization of governance structure, and the discriminating alignment.

3.2.1 The Basic Framework of Williamson's Theory of the Firm

Williamson's micro-analytic approach to the theory of the firm takes the transaction as the basic unit of analysis. It asserts that the choices of contractual form are mainly based on transaction cost economizing considerations (Williamson, 1979, p. 245). Williamson's theory owes much of its explanatory/predictive power to the development of "discriminating alignment" (Williamson, 1991) that defines the match between transactions and various governance structures. Specifically, the discriminating alignment consists of the following three critical elements: (1) dimensionalization of transactions—i.e., to name the key attributes across which transactions differ; (2) dimensionalization of governance structures—i.e., to describe the properties by which alternative modes of governance differ; and (3) applying the "discriminating alignment" hypothesis by demonstrating that different kinds of transactions are more efficiently governed by different modes of governance.

Williamson notes that the magnitude of the contractual hazards varies systematically with the attributes of transactions. Three attributes of transactions—i.e., asset specificity, uncertainty, and frequency—have been identified (Williamson, 1979) as being of primary importance. In particular, asset specificity has been the central construct of Williamson's theory as Williamson himself concurs that "the main factor to which transaction-cost economics appeals to explain vertical integration is asset specificity" (Williamson, 1986: p. 189).

On the governance sides, three generic governance structures— market, hybrid, and hierarchy—are identified and it is argued that these few generic modes of governance differentiate with each other by a syndrome of internally consistent attributes to which different adaptive strengths and weakness accrue. These attributes, as identified by Williamson (1991), are *intensive intensity*, *administrative control*, and *contract law regime*.

A final step of the "discriminating alignment", as we will see later, is then to work out the exact match between transactions (which differ in their attributes and adaptive needs) and governance structures (which differ in their costs and competencies to implement autonomous and coordinated adaptations), so as to effect an efficient alignment that serves the transaction cost economizing purpose. This logic is most dramatically worked out for the case when the condition of asset specificity is coupled with high external uncertainty. Specific assets open the door to opportunism. Due to bounded rationality, contracts are incomplete and must be renegotiated as uncertainty unfolds. If one party makes nontrivial specialized (non-redeployable) investments (including human capital) in support of the contract, the other party can hold him up by threatening to withdraw from the relationship, thereby opportunistically appropriating an undue share of the investor's "quasi-rents". This situation leads to inefficient outcomes, for example, a no-trade outcome, or an outcome characterized by inefficient haggling, or it may result in a suboptimal choice of investment. In the last case, fear of "hold up" *ex post* will affect investment choices *ex ante*. Note that asset specificity is a design variable, in the absence of appropriate contractual safeguards, the transacting parties may choose less specific—and therefore less specialized and less productive—technology (Riordan & Williamson, 1985). Efficiency dictates that a Pareto-improvement can then be made by vertical integration. In the first place, by pooling capital into a single enterprise in which the profits are jointly shared, the incentives for unproductive rent-seeking would be mitigated. Moreover, Williamson emphasizes that there is more to integration than the contraction of ownership rights: authority plays an important role as arbitrator in the face of conflicts and disputes over unforeseen contingencies, and there are qualitative and quantitative differences between the information structures that are available under market contracting and those that are available in the firm.

3.2.2 DimensionalizingTransaction

Dimensionalizing transactions was featured by TCE from the outset. As mentioned above, Williamson identified asset specificity, uncertainty (contractual disturbances), and frequency as the few critical attributes across which transactions differ. Of the three dimensions, Williamson emphasizes the first two, and in particular, he maintains that most critical dimension is that of asset specificity (Williamson, 1985b: p. 52).

A. Asset Specificity

Although a strong, if not overwhelming emphasis on asset specificity has been characteristic of Williamson's theory, the origin of the term (and a portion of the credit for developing the underlying ideas) should probably be ascribed to Klein, Crawford and Alchian[14] (1978). In their "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process", the three authors illustrate the problem of "hold up" and the appropriability of quasi-rent for transactions that involve "specific assets". According to them, once a specific investment is made, quasi-rents are created. The other party is thus induced to engage in opportunistic behaviour and/or costly haggling in an attempt to appropriate the value of the quasi-rent. The size of the quasi-rents of the specific asset is the difference of its value in current use and its next best use. The more specific the investment, the greater the quasi-rents, and the greater the incentive the other party would have to engage in the opportunistic appropriation of its value.

They further argue that in a world with only imperfect judicial systems, when a transaction involves specific investments, to avoid *ex post* opportunistic behaviour such as hold up, a firm tends to vertically integrate to organize the transaction internally rather than to organize the transition by market contract. In doing so, the costs of contracting are economized. In other words, as assets become more specific and more appropriable quasi rents are created, the costs of market contracting will generally increase more than the costs of vertical integration. Hence, ceteris paribus, we are more likely to observe vertical integration.

On the basis of Klein, Crawford and Alchian (1978), Williamson further refines the concept of "asset specificity". Specifically, Williamson defines asset specificity as "durable investments that are undertaken in support of particular transactions, the

[14] The three authors admit that their work is partially inspired by and based on Williamson (1971, 1975).

opportunity cost of which investments is much lower in best alternative uses or by alternative users should the original transaction be prematurely terminated" (Williamson, 1985b: p. 55). Put in a slightly different manner, "asset specificity has reference to the degree to which an asset can be redeployed to alternative uses and by alternative users without sacrifice of productive value" (Williamson, 1989: p. 142)—i.e., an asset is specific in the sense that it is specific to use or user. Various types of asset specificity have been identified (Williamson, 1985b: pp. 95-96; 1989: p. 143; 1991: p. 281)—physical, human, site specific, dedicated assets, brand name capital, and temporal—the optimal response to which varies somewhat but involves greater reliance on "administration." Generally speaking, by the condition of asset specificity, a bilateral dependency relationship develops between the transacting parties. Even though a large number of qualified suppliers could compete for the job before the contract is awarded, the *ex ante* large-numbers competitive bidding situation is effectively transformed during contract implementation into an *ex post* bilateral bargaining situation. Asset specificity thus gives rise to a "***fundamental transformation***" (Williamson, 1976, 1985b) in the contractual relation as bilateral dependency builds up. Identity thereafter matters which is to say that continuity of the relationship is valued.

Given the opportunistic inclinations of agents, it is argued that asset specificity tends to exacerbate transactional hazards, whence extra contractual and organizational safeguards are needed to support transitions of this kind. According to Williamson (1989: p. 143), "asset specificity not only elicits complex *ex ante* incentive responses but, even more important, it give rise to complex *ex post* governance structure responses". In other words, the response is either to design a more delicate *ex ante* incentive scheme in the contract, or to choose a more complex *ex post* governance structure. Given contract incompleteness and the imperfections of court ordering, Williamson (2005a) asserts that the choice of governance structure is principally an exercise of "private ordering", by which term it is meant that "the immediate parties to an exchange are actively involved in the provision of good order and workable arrangements" (Williamson, 2005a: p. 1) that realize mutual gains from trade.

B. Uncertainty

A second dimension of transaction is that of uncertainty. Williamson (1985b: pp. 56-59) identifies three types of uncertainty, the first two of which—primary and secondary uncertainties—were first defined by Koopmans (1985b). The primary uncertainty is of a state-contingent kind which reflects a lack of knowledge about states of nature, while the secondary uncertainty, by contrast, reflects a lack of knowledge about the actions of other economic actors and it arises "from lack of communication, that is from one decision maker having no way of finding out the concurrent decisions and plans made by others" (Tjalling Charles Koopmans, 1957: p. 162). Williamson (1985b) describes both primary and secondary uncertainties as 'innocent' or 'non strategic' forms of uncertainty and he highlights the existence of a third type of uncertainty, which is attributable to opportunism and is referred to as "behavioural uncertainty". Specifically, behaviour uncertainty concerns the difficulty in predicting the actions of other relevant actors, particularly in view of potential opportunistic behaviour such as strategic non-disclosure, disguise, or deliberate misrepresentation of information. In Williamson's view, the behavioural type of uncertainty is the key form of uncertainty relevant to the economic organization(Sutcliffe & Zaheer, 1998)[15].

It should also be emphasized that in Williamson's theory, the influence of uncertainty on economic organization is conditional (1985b: p. 59). Specifically, whatever the type of uncertainty, it will have little consequence in the face of low asset specificity, since in this case, the continuity has little value, adaptive capacities are not crucial, and new trading relations can be easily arranged. However, uncertainty will have a significant influence if the transaction is specific in nontrivial degree and supported by idiosyncratic investments. In this case, uncertainty imposes disturbance to the contract upon which bilateral adaptation is needed, and the results of maladaptation are considerable.

In short, given bounded rationality, uncertainty adds to the incompleteness of contract, and in conjunction with asset specificity, the number of consequential disturbances that impinge on a contract increases, it then become imperative that added governance supports are needed (Tadelis & Williamson, 2012).

3.2.3 Dimensionalizing Governance Structure

Whereas the dimensionalization of transaction received early and explicit attention, the dimensionalization of governance structure has been relatively ignored for quite a long time (Williamson, 1991). One of Williamson's contributions to the transaction costs theory of the firm, is to identify the few internally consistent attributes which describes the "***adaptive capacities***" of the three generic modes of governance—market, hierarchy and hybrid (Tadelis & Williamson, 2012; Williamson, 1985b,

[15] Helfat and Teece (1987) make a similar argument. They observe that both secondary and behavioural uncertainties are relevant (whereas primary uncertainty is less relevant) to vertical relationships, since vertical integration tend to reduce these two types of uncertainties as compared to the un-integrated alternative.

1991, 2010b). Specifically, the few dimensions are ***incentive intensity***, which is measured by the extent to which a technologically separable stage of economic activity appropriates its net profits; ***administrative command and control***, which is strong if successive stages are under unified ownership and are subject to coordination and dispute resolution by a common "boss"; and ***contract law regime***, which is strong under a legal rules (court ordered) contract law regime but is weak if disputes between successive stages are settled by private ordering, where the firm is its own final court of ultimate appeal.

Below, the discussions regarding the dimensionalization of governance structures will be organized in two parts. In the first part, we discuss the two types of adaptation problems in economic organization. In part two, we discuss how the three generic modes of governance differ in terms of the three attributes so as to realize different adaptive performance.

A. Adaptation as the Central Economic Problem

TCE takes adaptation as the central problem of economic organization. Williamson distinguishes two distinct types of adaptation—i.e., Hayek's (1945) *autonomous adaptation*, and Barnard's (1938) *coordinated adaption*—and he maintains that each adaptation has its role to play in a well-functioning economy.

The adaptations to which Hayek (1945) refers are those for which prices serve as sufficient statistics. In this type of adaptation, autonomous economic actors adjust spontaneously to parametric price changes so as to maximize their utility and profits, respectively and collectively. The marvel of the market thus resides in "how little the individual participants need to know to be able to take the right action" (Hayek, 1945: pp.526-527).

By contrast, the adaptations of concern to Barnard (1938) those among economic actors working within the same firm and through the use of administration. In Barnard's view, the marvel of hierarchy is that coordinated adaptation is accomplished not spontaneously but in a "conscious, deliberate, purposeful" way through administration (Barnard, 1938: p. 4).

Based on the distinction, Williamson demonstrates how each generic mode of governance is defined by the few internally consistent attributes to which different adaptive strengths and weaknesses accrue.

B. How the Three Generic Modes of Governance Differ

Broadly speaking, in Williamson's conceptions (Tadelis & Williamson, 2012; Williamson, 1991), markets and hierarchies are polar opposites in incentive intensity, administrative command and control, and contract law respects; and the hybrid is a compromise mode on all these attributes.

Presumably, the mechanisms that operate at the interface in support of the transactions (between two successive stages) reflect these differences (see figure 3-1 and figure 3-2). Let's start with the two polar modes.

If a transaction is mediated through the market, parties to the transaction will negotiate the contract in a hard-headed way, with high-powered incentives and in the absence of administrative involvement. The supplier receives a fixed payment for delivery of the prescribed goods and services, changes require renegotiation, and disputes are dealt with by courts which apply the appropriate legal rule (classical contract law) (Macneil, 1974) to award money damages. Given ownership autonomy, each party appropriates its own net receipts and each adapts to price signals in the market on its own motion. Market mediated exchange obtains. Autonomous adaptations are served in the process.

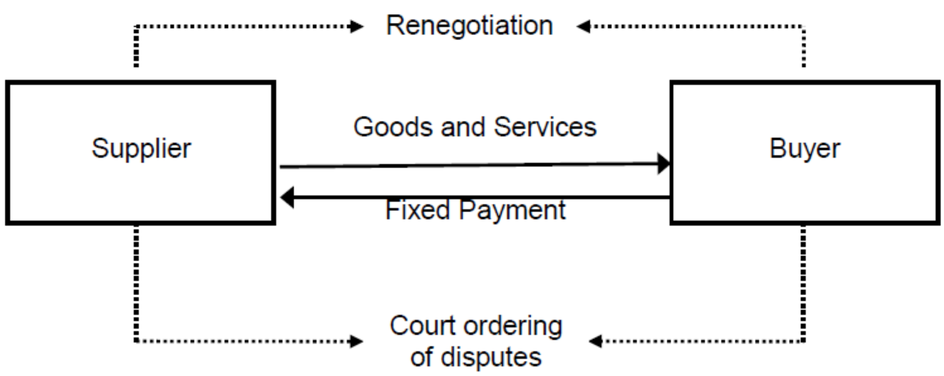


Figure 3- 1: Market Mediated Transaction

Source: Figure 1, Tadelis & Williamson(2012)

By contrast, in a hierarchy-mediated transaction, independent ownership gives way to unified ownership by which a peak coordinator is created to manage the interface and to promote coordinated adaptation. Each stage reports and receives administrative direction and control from the peak coordinator. Coordinated adaptation is made with reference to expected net gains (cost-plus) and is done in a timely way (without adversarial bargaining) on the decision of the interface coordinator. To be more exact, the payment between supplier and buyer is made from a common treasury, the effect of which is to provide low-power incentives (mainly of a cost-plus kind) that elicit greater cooperation and uncontested compliance by each stage. Disputes are also mediated by the interface coordinator on the merits, and such private ordering is supported by the contract law regime of "forbearance" (Williamson, 1991) . Specifically, whereas courts routinely grant standing to autonomous firms should there be disputes between them (e.g., dispute over prices, failure of quality, damages due to delay of delivery, etc.), by the implicit contract law of internal organization (i.e., forbearance), courts will refuse to hear disputes between one internal division and another over identical technical issues. Access to the courts over these technical issues being denied, the parties must resolve their differences internally. Accordingly, the courts are largely deferential, and in many cases, "hierarchy is its own court of ultimate appeal" (Williamson, 1991: p. 274).

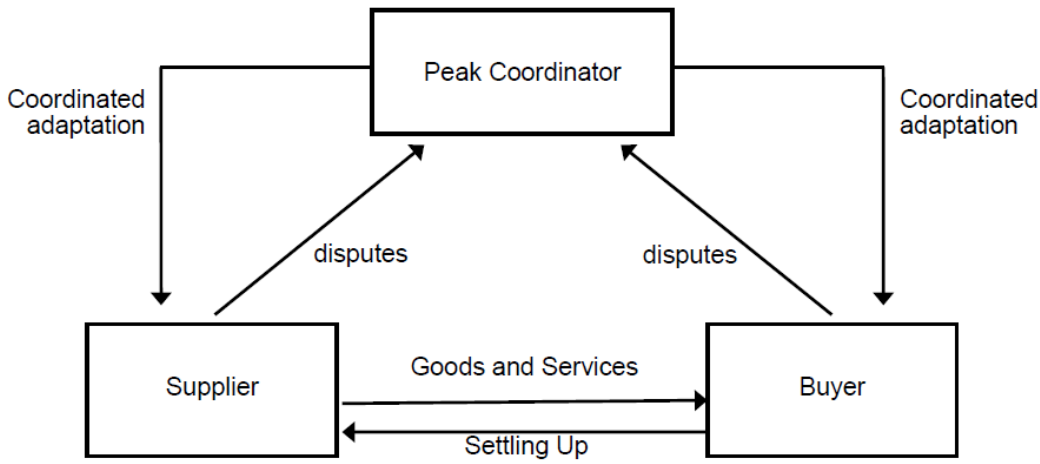


Figure 3- 2: Hierarchy Mediated Transaction

Source: Figure 1, Tadelis & Williamson (2012)

A third type of generic governance structure is that of hybrid. According to Williamson (1991, 2005a), the hybrid is a compromise mode that is located between market and hierarchy on all three attributes. It is characterized by semi-strong incentives, an intermediate degree of administrative apparatus, and works out of a semi-legalistic contract law regime. It works well, but not surpassingly well, in both autonomous and coordinated adaptation respects. The viability of the hybrid turns crucially on the efficacy of credible commitments (penalties for premature termination, information-disclosure and verification mechanisms, specialized dispute settlement, and the like), the cost effectiveness of which varies with the attributes of transactions (Williamson, 1991; Claude Menard, 2004), and the contract law regime applicable to hybrid mode is that "neoclassical contract law" (Macneil, 1978) in which contract is treated less as legal rules and more as a "framework" (Llewellyn, 1931: p. 736) to organize their relationship in a more elastic and a less legalistic manner (Galanter, 1981).

To sum up for the above discussion, we present the key attributes of (spot) market, hybrids, and hierarchies in table 3-1.

Table 3- 1: Distinguishing Attributes of Market, Hybrid, and Hierarchy Governance Structures*

	Governance structure		
Attributes	Market	Hybrid	Hierarchy
Incentive intensity	++	+	0
Administrative controls	0	+	++
Contract law	++ (classic contract law)	+ (neoclassic contract law)	0 (forbearance)
Performance			
Autonomous Adaptation (A)	++	+	0
Coordinated Adaptation (C)	0	+	++

* ++= strong; += semi-strong; 0= weak

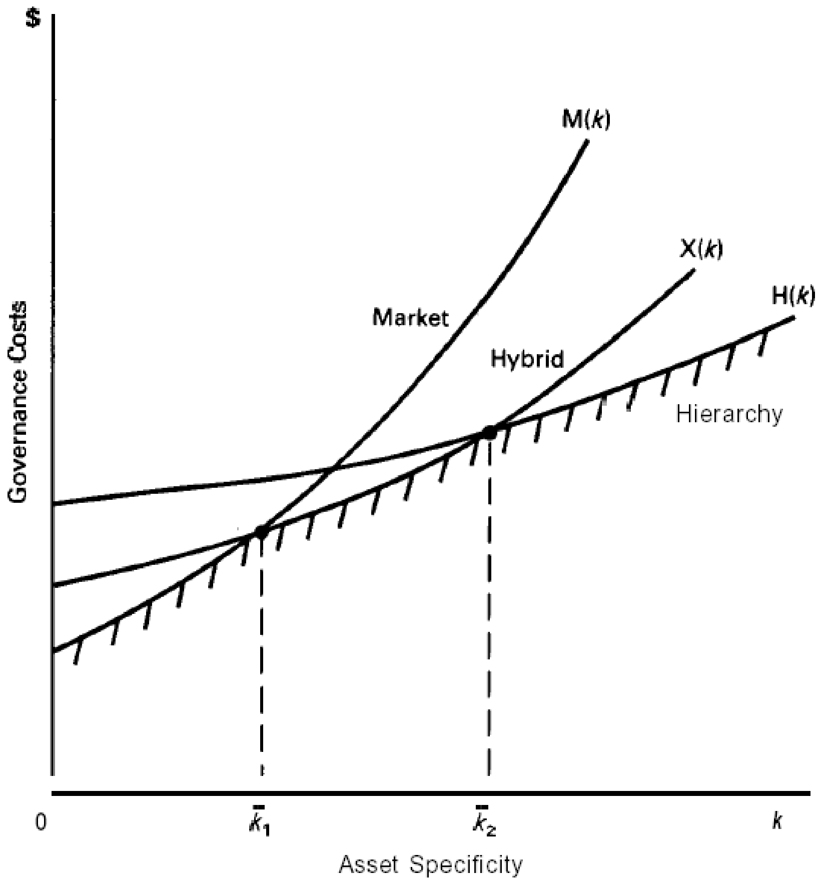
Source: Table 1, Williamson (1991)

3.2.4 Discriminating Alignment

In TCE, adaptation is treated as the main problem of economic organization. However, as (1) transactions differ in their adaptive needs (autonomous or coordinated), (2) governance structures differ in the costs and adaptive capacities, and (3) maladaptation is inefficient and undermines the viability of a business firm, economizing is central. This is captured in the "discriminating alignment hypothesis"(Williamson, 1991: p. 277) which states that: "transactions, which differ in their attributes, are aligned with governance structures, which differ in their costs and adaptive capacities to implement autonomous and coordinated adaptations, so as to effect an efficient (transaction cost economizing) alignment".

Note that (1) markets enjoy the advantage of autonomous adaptation for transactions that are supported by generic assets, (2) the need for coordinated adaptation increases as the supporting assets become more specific, and (3) the bureaucratic costs of hierarchy, among which there is the loss of incentive intensity, are a deterrent to integration except as coordinated adaptation benefits are more than offsetting.

Figure 3-3 illustrates the trade-offs using k is an index of asset specificity. Efficient alignment is accomplished by assigning transactions for which asset specificity is low to markets, transactions for which asset specificity is medium to hybrid and transactions for which asset specificity is high are assigned to hierarchy.



Note: The governance costs of the three generic modes of governance—market, hierarchy, and hybrid—are written as a function of asset specificity (*k*) and a vector of shift parameters (*θ*) respectively, i.e., M= M(*k*; θ), H= H(*k*; θ) and X(*k*; θ).

Figure 3- 3: Governance Costs as a Function of Asset Specificity

Source: Figure 1, Williamson (1991)

Market enjoys the advantage when asset specificity is negligible ($M(k)<X(k)<H(k)$ for $k<\bar{k}_1$), as the disturbances for which adaptations are needed are signalled by changes in relative prices to which buyers and sellers respond autonomously. The use of hierarchy in these circumstances would entail a loss of incentive intensity and the added costs of mediating the interface with a coordinator (as shown in Figure 3-2) serve no purpose.

By contrast, given contractual incompleteness (by reason of bounded rationality), if the transactions are supported by significant investments in transaction specific assets, consequential disturbances can be expected upon which coordinated adaptations are needed. Such transactions will benefit from unified ownership and coordinated adaptations as implemented by hierarchy ($H(k)<X(k)<M(k)$ for $k>\overline{k}_2$).

Williamson emphasizes (1991) in particular that the lowering of incentive associated with hierarchy is not always an unwanted consequence of unified ownership; rather, it is adopted purposefully to elicit greater cooperation to a coordination adaptation (and the side effects are checked by added internal controls). However, the lowering of incentive intensity incurs added bureaucratic costs and reduced productive efficiency. Hierarchy is thus usefully thought of as "the organization form of last resort" (Williamson, 1991: p. 279; 2005b: p. 53).

Finally, when asset specificity is in the medium range, the requisite adaptations to disturbances are neither predominantly autonomous nor bilateral, but require a mixture of each, Transactions of this kind are candidates to be organized under the hybrid mode. Over some intermediate range of *k*, the mixed adaptation (Autonomous/Coordinated) that hybrids afford could well be superior to the A-favoring or C-favoring adaptations supported by markets and hierarchies, respectively ($H(k)<M(k)$ and $H(k)<H(k)$ for $\overline{k}_1< k <\overline{k}_2$).

3.3 Formalization of TCE: The Grossman-Hart-Moore Model

As observed by Williamson (2000, 2010b), transaction cost economics has undergone a natural progression from informal, pre-formal, to semiformal, and finally to full formalization. Full formalism of transaction cost economics began in 1980s and is still in progress (Bajari & Tadelis, 2001; J. Levin & Tadelis, 2010; Tadelis, 2002; Tadelis & Williamson, 2012). In particular, the paper by Grossman and Hart (1986), and the follow-on paper by Hart and Moore (1990) (known as the GHM model)—which started the (new) "property right theory" literature (N. J. Foss, 2010b; J.T. Mahoney, 2005)—have been widely viewed as path-breaking works in this regard.

Below, we will use a simplified model together with a few numeric examples to illustrate the basic insights of GHM model. As will be clear later on, although GHM model shares with Williamson's TCE an appreciation for contractual incompleteness and an emphasis on relation-specific investment, there are fundamental differences between these two approaches. Given these differences, GHM model is at best a partial formalization of Williamson's theory; and indeed, the two approaches are better understood as two distinct theories.

3.3.1 A Simplified GHM Model

The following simplified model and numeric example are adapted from Tirole (1986, 1988) and Holmstrom & Tirole (1989) which capture the spirits of the much technical Grossman-Hart-Moore model (Grossman & Hart, 1986; Hart, 1995; Hart & Moore, 1990). For an excellent synopsis of the technical details of the formal model, see chapter 2("*The Property Rights Approach*") in Hart (1995).

Let us start with a numeric example (Holmstrom & Tirole, 1989).

A. A Numeric example

A.1 Basic Setup

A buyer and a seller, denoted B and S, each owning their own assets (physical as well as human), signed a contract at date 0 for exchanging a unit of a good at date 1.

Both of them are aware of the possibility that an improvement could be made to the contracted good (as a result of technological innovation after date 0). But at date 0, they cannot foresee the nature of such improvement. Thus, only a basic design is contracted for.

Denote the buyer's benefit from a design improvement by v and the seller's cost of implementing the design change by c. These figures are net of benefits and costs from the basic design.

The values of v and c are uncertain at date 0 (but both parties have the same information about the distribution of the values, which in turn depends on the choices of the parties involved), while their actual values will be realized at date 1.

At date 1, both parties will be able to observe the realized values of v and c, but assume that the values are not verifiable by a third party so that the possibility of contingent contracting is precluded (by reason of non-enforceable).

For simplicity, assume there are only two possible values for v, 20 and 40; and two for c, 10 and 30.

The buyer can influence the outcome of v by making an unverifiable investment after date 0.

Let $x = prob(v = 40)$ represent the buyer's investment decision and assume the cost is $10x^2$, i.e., by making an unverifiable investment of $10x^2$ after date 0, the buyer's expected outcome at date 1 would be:

$$v = \begin{cases} 20 & \text{with a probability of } 1 - x \\ 40 & \text{with a probability of } x \end{cases}$$

Similarly, the seller have a choice such that

$$c = \begin{cases} 10 & \text{with a probability of } y \\ 30 & \text{with a probability of } 1 - y \end{cases}$$

at the cost of $10y^2$

The investment technology can be interpreted as investing in flexibility, since a higher investment increases the probability that the improvement that comes about can be used (either by a higher v or by a lower c). For instance, an employer (a buyer) can train his workers to adjust to changing technologies.

A.2 Ownership and Assets

A central assumption of the GHM model is that contracts are necessarily incomplete in the sense that the allocation of specific control rights cannot be specified for all future states of the world in a legally enforceable way. Following legal convention, ownership is defined as the possession of residual rights of control, that is, rights to control the uses of assets under contingencies that are not spelled out in the contract. According to Grossman and Hart (1986), it is the distribution of residual rights of control that determines the boundaries of the firm. In other words, a firm is defined as a bundle of jointly owned physical assets, and the basic distinction between an independent contractor and an employee, turns on who owns the physical assets that the agent utilizes in his work. An employee, unlike an independent contractor, usually does not own his tools.

Another critical assumption of the GHM model is that unlike physical assets, human capital is an inalienable asset. To be more exact, the ownership of human capital cannot legally be transferred, which places particular constraints on contracting. Integration involves transformation of ownership of physical capital, but not of human capital. If one invests in one's own human capital, the investment costs were borne by the investing person irrespective of ownership structure. Put differently, the service of human capital assets could not be compensated for by incentive contracts because of enforcement (non-verifiable) problems. For example, a contract that specifies that the buyer pays the costs of the seller (in the form of non-verifiable investment in human capital which demand exertion of efforts) if a design change is implemented is subject to misuse by the seller—he can load costs onto the buyer which are unrelated to the design change, or he can disguise shirking as bad luck and over-claim his efforts. In short, at point out by Holmstrom and Tirole (1989: p. 70), separating the return streams of a productive asset from the decision rights of the asset is simply not feasible, because the return streams cannot be verified.

A.3 Three Different Cases

Ownership determines who has the right to decide whether the design change is implemented. It also determines how the surplus of the trade is divided.

Three different cases are of interest. In the non-integration case, each party has the right to veto the change, any change to the original contract must be resolved through negotiation. In the case of buyer-integration, the buyer can implement the change by fiat and in the case of seller-integration the reverse is true.

1. Non-Integration

There are four possible outcomes for (v,c):

$$(v,c)=\{(20,10),(20,30),(40,10),(40,30)\}$$

Assuming that bargaining is costless, in three of the four cases, the new design will be implemented as both parties can observe v and c and implementation is efficient. Only when the outcome (20, 30) turns up, will the new design not be implemented. Further assume that both parties have ***equal bargaining power*** such that a Nash bargaining solution could be predicted—i.e., the surplus from implementation of the new design will be divided equally.

The rule of dividing the surplus is given as:

$$\frac{v-c}{2} \text{ if } v \geq c \text{ and otherwise equals zero}$$

The probability distribution of the outcomes is then given as:

c \ v	20	40
10	$(1-x)\,y$	xy
30	$(1-x)\,(1-y)$	$x(1-y)$

For the buyer, the optimization problem is:

$$\max_x \left[E_B - 10x^2 \right] \quad \text{s.t. } y = y^* \tag{3.3.1}$$

where E_B is the expected benefit of the investment, and

$$E_B = \frac{(20-10)(1-x)y + (40-10)xy + 0(1-x)(1-y) + (40-30)x(1-y)}{2} = 5y + 5xy + 5x \tag{3.3.2}$$

Substitute (3.3.2) into (3.3.1), the optimization problem for the buyer turns into

$$\max_x \left[5y + 5xy + 5x - 10x^2 \right] \quad \text{s.t. } y = y^* \tag{3.3.3}$$

The first order condition for the maximization problem implies that:

$$\left[5y + 5xy + 5x - 10x^2 \right]'_x = 0 \quad \text{s.t. } y = y^* \tag{3.3.4}$$

Therefore, we have:

$$x^* = \frac{y^* + 1}{4} \tag{3.3.5}$$

Similarly, the optimization for the seller is

$$\max_{y}\left[5y+5xy+5x-10y^2\right] \quad \text{s.t. } x=x^* \tag{3.3.6}$$

Solving the maximization problem, we have:

$$y^*=\frac{x^*+1}{4} \tag{3.3.7}$$

The Nash equilibrium for the investment choices will then be:

$$y^*=\frac{x^*+1}{4}=\frac{\frac{y^*+1}{4}+1}{4}=\frac{y^*+5}{16} \tag{3.3.8}$$

Therefore,

$$y^*=x^*=1/3 \tag{3.3.9}$$

The social surplus, net of investment costs, would then be $W^{NI}=\frac{50}{9}$ (where NI stands for non-integration).

Let's compare the result for the non-integrated form of organization with that for the socially optimal level.

The socially optimal investment level is defined by the following maximization problem:

$$\max_{x,y}\left[10y+10xy+10x-10x^2-10y^2\right] \tag{3.3.10}$$

The first order conditions for the maximization are:

$$\begin{cases}\left[10y+10xy+10x-10x^2-10y^2\right]'_x=0\\ \left[10y+10xy+10x-10x^2-10y^2\right]'_y=0\end{cases} \tag{3.3.11}$$

Solving the maximization problem, we have:

$$\begin{cases} x^*=1 \\ y^*=1 \end{cases} \tag{3.3.12}$$

The social surplus, net of investment costs, would then be W^*=10.

<u>2. Buyer Integration</u>

In the case of buyer-integration, the buyer can implement a change by fiat.

Under this circumstance, as the residual claimer, the buyer's net return at date 1 is *v*-*c*. The seller, now the employee, will merely cover his labor costs and hence earn zero returns at date 1. Consequently, he will have no incentive to invest in the relationship (y = 0). The cost of implementing the new design will therefore equal 30 for certain.

The probability distribution of the outcomes in this case is given as:

c \ *v*	20	40
10	0	*0*
30	$1-x$	x

For the buyer, the optimization problem is:

$$\max_x \left[E_B - 10x^2 \right] \tag{3.3.13}$$

where E_B is the expected benefits of the investment, and

$$E_B = (40-30)x = 10x \tag{3.3.14}$$

Thus, the buyer's net returns form investing x are $10(x-x^2)$ (if the value of the new design is 40 it will be implemented and the buyer will receive a net return of 10).

Solving the optimization problem for the buyer (now the residual claimant), we have x^*=1/2 and accordingly the social surplus in this case is W^{BI}=2.5 (where BI stands for buyer integration).

<u>3. Seller Integration</u>

In the case of seller-integration, the seller can implement a change by fiat.

Under this circumstance, the seller's net return at date 1 is v-c. The buyer, now the employee, will merely cover his labor costs and hence earn zero returns at date1. Consequently, the buyer will have no incentive to invest in the relationship (x = 0). The value of the new design will be 20 for certain.

The probability distribution of the outcomes in this case is given as:

c \ v	20	40
10	y	*0*
30	$1-y$	x

For the seller, the optimization problem is:

$$\max_{y}\left[E_S - 10y^2\right] \tag{3.3.15}$$

where E_S is the expected benefits of the investment, and

$$E_S = (20-10)y = 10y \tag{3.3.16}$$

Solving the optimization problem, we have: $y^* = 1/2$ and the social surplus in this case is W^{SI}=2.5 (where SI stands for seller integration).

A.4 Remarks

Several remarks can be made with regard to the above example.

Firstly, in the above case, the social surplus for the two forms of integration are identical, suggesting that it does not matter who takes over whom. But that is merely an artifact of symmetry. As will be clearer later on, in the GHM model, the social welfare for the two forms of integration will generally be different. To be more exact, in Williamson's model, integration means unified ownership—i.e., the buyer and the seller are merged under a unified management by which cooperation is effected, and it doesn't matter who integrate whom; while in the GHM model, integration is directional, that is, it matters who takes over whom since the social welfare results of buyer-integration and seller-integration will generally be different.

Secondly, the example demonstrates that in a world of incomplete contracts, the allocation of residual rights via ownership will affect investments in relationship-specific assets and thereby efficiency. Specifically, integrated and non-integrated modes of transaction will imply a different division of the surplus from the relationship *ex post*, therefore leading to different levels of investment in relationship-specific asset *ex ante*.

Thirdly, in Williamson's theory, it is generally argued that hierarchy is better able to overcome the contractual hazards (e.g., hold up, haggling etc.) associated with asset specificity; while in the above case, it is shown that even in the face of relationship-specific investment, market contracting (non-integration) could still be more efficient than integration. In fact, in the above example (and in GHM model more generally), specific conclusions regarding the desirability of integration depend on the values of parameters. For instance, if the higher value of the cost of design change is 11 instead of 30, then buyer integration is the best choice as in this case, reducing costs become less important than increasing value. Similarly, changes in the costs of relation-specific investments would also affect the desirability of a specific choice.

Finally, in Williamson's theory, it does not matter which type of asset specificity is involved, as each of them would lead to similar results. While in the above example, ***the choice of organization mode is quite sensitive to the type of assets involved***. To be more exact, the result of the above example (and in GHM model more generally) depends critically on the role of human capital, since ownership of human capital cannot legally be transferred, which places particular constraints on contracting. This means, in the GHM model, (non-contractible relationship) specific investments refer mainly to non-transferable human assets whose services could not be compensated for by incentive contracts because of enforcement problems. By contrast, if the investments in the above example are instead financial outlays, the costs of which are necessarily borne by the owner, the seller-employee under buyer integration would have no objections to incurring these investment costs, because the investment does not demand extra effort on his part, and the money would not be out of his pocket. Consequently, buyer integration (or seller integration) would lead to the socially-optimal result and be superior to non-integration, as predicted by Williamson. It should be noted that only this version of the example matches Williamson's vision of the benefits of integration. Specifically, in that view, "unified ownership is normally thought of as a means by which to effect cooperation" (Williamson, 2000: p. 606) and it is generally assumed that integration tends to reduce opportunistic tendencies of the parties. While in the earlier examples, this is not the case. Summing up, the example and the variation fit the general insights of the GHM models that "*human capital investment and use is best encouraged by independent ownership, while coordination of (physical) capital investments is better accomplished by joint ownership*" (Holmstrom & Tirole, 1989: p. 72) .

B. A Simplified Model

Above, we illustrate some of the basic insights of the GHM model by a numeric example. To further demonstrate the more general insights of the GHM model, we will now examine a simplified model adapted from Tirole (1988).

B.1 Basic Setup

The setup is roughly the same as the above examples. To repeat, a buyer and a seller, denoted B and S, each owning their own assets (physical as well as human), signed a contract at date 0 for exchanging a unit of a good at date 1. Trading is not an issue, as the parties agree that the good is to be exchanged in any case. The only uncertainty concerns the final specification of the good. A basic design is contracted for at date 0, but both parties are aware that an improvement could be made to the contracted good at date 1 that could not be described at date 0.

The second-period cost to the seller, c, is greater than zero. For simplicity, we suppose that c is known at date 0 and is independent of the particular improvement. The buyer picks an investment after date 0. His second-period benefit for the improvement is $v > c$ with probability x and 0 with probability $1 - x$, i.e.,

$$v = \begin{cases} v > c & \text{with a probability of } x \\ 0 & \text{with a probability of } 1-x \end{cases} \tag{3.3.17}$$

The cost of buyer's investment, I, is equal to $x^2/2$. It is not clear to outsiders which level of investment has been chosen, so that the parties cannot contract on it. Note that v and c are extra return and cost (beyond the values corresponding to the basic design).

B.2 Socially Optimal Outcome

Let's first look at the social optimum in this model. Obviously, the design improvement should be made if and only if the buyer has value v. The optimal investment is then given by:

$$\max_x \left[x(v-c) - \frac{x^2}{2} \right] \tag{3.3.18}$$

Solving the optimization problem, we have $x^* = v - c$. The joint surplus is $W^* = (v-c)^2/2$.

B.3 Three Different Cases

Assuming that the parties are self-interested, we will now consider three different forms for organizing the transaction: non-Integration (unconstrained bargaining), buyer integration (where buyer has the right to decide whether the design improvement is to be made) and seller integration (where the seller has the right to decide whether the design improvement is to be made). As before, we assume *bargaining is costless.* Additionally, in the case of non-integration, we assume *both parties have equal bargaining power*; and in the last two cases, we assume that *the party who has the authority can bargain and offer to give this authority away*. For instance, in the case of buyer integration, the buyer (now the authority and the residual claimant) can offer not to impose the improvement on the supplier if the latter gives him a transfer in exchange). In any bargaining situation, any gains from trade are assumed to be shared equally. Finally, we assume that among the three forms of organization, the parties choose the one that maximizes expected joint surplus, on the grounds that gains from changing the organization form to a more efficient one can always be redistributed through a transfer at date 0.

1. Non-Integration

Under non-integration, the parties will implement the design change if and only if $v > c$. Each gets $(v-c)/2$. So the buyer's investment solves

$$\max_x \left(\frac{x(v-c)}{2} - \frac{x^2}{2} \right) \tag{3.3.19}$$

Hence,

$$x^{NI} = \frac{v-c}{2} = \frac{x^*}{2} \tag{3.3.20}$$

Obviously, in this case, the investment is less than the socially desired level.

Joint surplus in this case is:

$$W^{NI} = x\left(v-c\right)-\frac{x^2}{2}=\frac{3\left(v-c\right)^2}{8}=\frac{3W^*}{4} \tag{3.3.21}$$

2. Seller Integration

The seller does not make any relationship-specific investment in this case. For the seller, choosing not to implement the design change is seemingly the less costly action for him. Suppose initially, the supplier chooses not to implement the design change, let's see what would happen. As noted by Grossman and Hart (1986), authority does not mean that the concerned parties do not negotiate *ex post*. The preferred decision of the party who has authority could be very costly to the other party. If some alternative decision may be mutually advantageous, the party with authority can coerce some benefits by not exercising this authority. In other words, authority puts the party with it in a better bargaining position. In our case, if supplier chooses not to implement the design change, both parties receive 0 from their relationship on date 1. However, there is in fact a chance for mutually advantageous improvement on the outcome. The buyer can offer to give the supplier (now the authority and residual claimant) a transfer if the supplier chooses instead to implement the design change.

For the buyer, the optimization problem is exactly the same as that in (3.3.19). Specifically, the buyer would offer half of the extra gain $(v-c)/2$ to the seller (the authority) if the seller choose instead to implement the design change. In short, supplier integration in this simple model is equivalent to non-integration, because "the status-quo point is the same" (Tirole, 1988: p. 32). Given the equivalence, $x^{SI}=x^{NI}$, $W^{SI}=W^{NI}$. Again, as the buyer's investment is "half-expropriated," the buyer will naturally underinvest.

3. Buyer Integration

In the case of buyer integration, the seller (now the employee) the employee will merely cover costs c and hence earn zero returns at date1. In this model, the seller does not invest in relationship-specific human capital assets.

The optimization problem for the buyer is given by:

$$\max_x \left[x(v-c)-\frac{x^2}{2} \right] \tag{3.3.22}$$

which is exactly the same as (3.3.18).

Hence, we have $x^{BI} = x^* = v - c$, and $W^{BI} = W^* = (v-c)^2/2$.

If we compare the outcomes of the three different cases, it is easy to see that in the above model, the buyer-integration is the optimal ownership structure, dominating non-integrated as well as the seller integration.

B.4 Remarks

The above simplified GHM model indicates that integration is directional —it matters whether A acquires B or B acquires A—as the social welfare outcomes of the two forms of integration are different.

The model also confirms the underinvestment result of the previous numeric example. In fact, it is a general conclusion (Che & Sakovics, 2008; Tirole, 1986) of the GHM model that in the face of non-contractible relationship specific investment, market transactions would generally end up with underinvestment, as the non-contractibility of relationship-specific investment prevents parties from negotiating meaningfully over the socially-optimal decision *ex ante* .

In the above model, buyer-integration provides a socially-optimal organizational solution to the hold up problem, but this is a special case rather than a general result. More generally, in the GHM model, the efficiencies of alternative ownership structures depend critically on the particular bargaining solution assumed (as reflected in the choice of specific parameters of the model).

In the above model, the exposures to hold up problem are asymmetric, as the buyer needs to choose a level of contractible relationship-specific investment whereas the seller does not have to. Accordingly, assigning the ownership of assets to the party whose investment is non-contractible realizes socially optimal result. This result reveals the main tenet of the GHM model that asset ownership can serve to reduce the owner's exposure to hold-up in that the owner of an asset will have a stronger incentive to make asset-specific investments, knowing that he has residual property rights (Che & Sakovics, 2008).

In the more general case that both parties invest in non-contractible relationship specific human capital, transferring ownership of physical assets from one party to another has a benefit—encouraging investment by the acquirer—and a cost—

discouraging investment by the acquired. The trade-off determines ownership structures and firm boundaries (Grossman & Hart, 1986).

Overall, the general upshot of the GHM model (Aghion & Holden, 2011; Antras, 2005; N. J. Foss, 2000b; Hart, 1995) is that the importance of asset ownership derives from the fact that the incentive of an agent to undertake a relationship specific non-contractible investment (e.g., the exertion of effort or investment in human capital) depends on who owns the asset. By affecting the *ex post* division of surplus, the allocation of residual rights of control has a critical effect on each party's *ex ante* incentives to invest, which in turn determine the size of the surplus to be divided. Efficiency then dictates that the *residual rights of control (i.e., ownership) should be assigned to the agent whose investment in non-contractible relationship specific investment (mainly human capital) contributes most to the value of the relationship*[16]. This is the case not because opportunistic incentives can be removed or avoided by integration; rather, it is because integration shifts (part of) the incentives for opportunistic behaviour by internalizing the costs. Given this, the parties should choose the ownership structure that—through its impact on incentives—minimizes the consequences of opportunism (efficiencies losses).

Relative to the work of Williamson and his associates, the main contributions (Foss, 2000; Hart, 1991; Holmstrom & Roberts, 1998) of the GHM model consist in its *clearer definitions of the boundaries of the firm and authority* (i.e., the boundary of a firm is defined in terms of the residual rights of control over physical assets), *a more consistent treatment of the costs and benefits of integration* (the GHM model uses the same concept of residual rights of control to explain both the benefits and the costs of integration; in particular, the costs of integration are explained as exogenous without invoking such notions as "bureaucracy costs") and arguably *an improved understanding on the issue of "who should integrate whom"*, all of which are cast consistently in terms of the single unifying principle of maximizing joint surplus of a relation through the choice of ownership structures.

[16] It has been noted (Langlois, 1997) that the basic sight of the GHM model is quite similar to that of the measurement costs approach associated with Yoram Barzel (1982; 1987; 2005). In Barzel's story (1987), in a two-party team production, if the output of one of the parties (indeed, contribution to the team output) is hard to measure/monitor, the party is tempted to shirk; in addition, if the shirking party's contribution to joint quasi-rents is large, it is efficient to assign the residual rights to this hard-to-measure party, who is then effectively disciplined by the desire to maximize residual income.
Although not clearly spelled out, Barzel's story is also one of incomplete contracts. Routine tasks are generally easy to monitor. The less routine the agent's task in team production— the larger the uncertainty in the tasks the agent may be called upon to perform — the harder to measure/monitor the agent and the harder to specify in a contract what the agent is supposed to do.

3.3.2 The Differences between the GHM Model and Williamson's Theory

Above, we illustrate the basic insights of the GHM model. As it becomes clearer now, although GHM model shares with Williamson's TCE some commonalities, there are fundamental differences between these two approaches. We will now discuss more explicitly these differences.

First of all, while transaction cost economics identifies *ex post* adaptation as the central problem of economic organization, the GHM model tends to focus exclusively on the problem of *ex ante* alignment of incentives to invest in non-contractible specific assets (Tadelis & Williamson, 2012), mainly of the intangible (human asset) kind, and only through the allocation of residual rights of control[17] (Holmstrom & Roberts, 1998). To put this somewhat differently, TCE holds that mal-adaptation in the contract execution interval is the main source of inefficiency (unproductive rent-seeking haggling over appropriable quasi-rent), whereas the GHM model eliminates the *ex post* mal-adaptation by the assumptions of common knowledge and costless *ex post* bargaining, and all inefficiencies in the GHM models have been reduced to those associated with *ex ante* misalignment of incentive (Gibbons, 2005; Williamson, 2000). It should be noted that a focus on *ex ante* incentives is at the core of most agency-based theories, on which the GHM model is deeply rooted (Tadelis & Williamson, 2012).

Together with the shift of focus in the process of formalization, much of the richness in Williamson's theory has been left out from the GHM model (N. J. Foss, 2000b; Kreps, 1996; Williamson, 2000). To be more exact, the GHM model is property rights and property rights only construction (Holmstrom, 1999), in which a Pareto-improvement may be brought about by reallocating residual rights of control, but changes in organization structure, administration controls and information channels are not likely to have welfare consequences. Transaction costs economics, by contract, maintains that the few generic modes of governance—spot market, hierarchy, and hybrids—differ systematically by a syndrome of attributes to which distinctive strengths and weaknesses accrue. Apart from incentive intensity, there are administrative controls (accordingly, different information structures and adaptive/coordination capacities), and different contract law regimes (accordingly, access to courts). Therefore, in the Williamson's theory, residual rights of control matter, but incentives are more than residual rights of control, and the differences

[17] Holmstrom and Roberts (1998) observed, with regard to the GHM model, that "investment incentives are not provided by ownership alone" and that "firm boundaries are responsive to more than investment incentives".

between the few generic modes of governance are more than the difference in incentive intensity; changes in organization structure, administration controls and information channels may have substantial consequences.

Third, the way that the GHM model deals with transaction costs is obviously different from that of Williamson. In fact, it could even be argued that that the GHM model deals with transaction cost in a single-minded manner (Tadelis & Williamson, 2012). On the one hand, GHM assumes that relationship-specific investment in human capital is not contractible, which means the effort and actions of relevant parties who work towards achieving the desired goals *cannot be specified ex ante at any cost*; on the other hand, it also assumes the ex post bargaining is costless, and if fact, all other possible categories of transaction costs (such as the costs of measurement) have been assumed to be zero. In a more friendly understanding, the GHM models tends to focus on a very specific kind of transaction cost (indeed, efficiency loss associated with misalignment of incentive to invest in relationship-specific human asset), and following the tradition of the agency-based literature, transaction costs are described as a situation in which the underlying circumstances (in particular, the information structure) has made the transaction difficult rather than as concrete costs under any substantiated heading. TCE, by contrast, focuses explicitly on few measurable dimensions over which transactions differ, with emphasis on identifying how different kinds of transactions are discriminately allocated to different governance structures. This accounts for much of its predictive content.

Fourth, whereas Williamson clearly rationalizes contractual incompleteness on the ground of bounded rationality (Williamson, 1985b), the theorists working with the GHM models tend to deny the need for a notion of bounded nationality (N. J. Foss, 2010a; N. J. Foss & Klein, 2008b). Specifically, Hart (1990) argues that bounded rationality may not be necessary at all, because its role can be replaced by the more tractable notion of asymmetric information, particularly in the form of non-verifiability to a third party (e.g., a judge). In fact, as have been noted by some scholars (e.g., N. J. Foss, 2010a; Pagano, 2007), in the GHM models, apart from the particular type of bounded rationality (non-verifiability) that makes third-party enforcement impossible (to be more exact, the asymmetric information between the participating parties and the third-party enforcer), in other respects, agents are endowed with a "super-rationality" (Pagano, 2007: p.21) considerably greater than that of the traditional neoclassical individuals. Specifically, by the assumption of "common knowledge"[18], agents not only maximize their own utility, but also fully anticipate the consequences of the maximizing behavior of the other contracting agents; in this spirits, they allocate the residual rights of control and invest in their respective non-contractible human capital in such a way that a second-best allocation of ownership of physical assets is achieved under contractual incompleteness.

Fifth, as we have seen, in the GHM models, integration is directional, because buyer-integration and seller-integration imply different *ex post* divisions of the surplus from the relationship, therefore leading to different levels of investment in contractible relationship-specific human asset *ex ante*. By contrast, in Williamson's theory, integration means unified ownership—i.e., the buyer and the seller are merged under a unified management, by which cooperation is effected, so the direction of integration doesn't matter. To GHM theorists, the unified ownership argument is problematic because it "does not explain how the scope for such behaviour changes when one of the self-interested owners become an equally self-interested employee of the other owner" (Grossman & Hart, 1986: p.691). Whereas to Williamson, there is more to integration than the alignment of incentive through the allocation of residual rights of control; integration also implies common ownership and unified management by which cooperation is effected—in particular, authority is now the interface coordinator and arbitrator, and there is a different information structure. Given these, the directional integration predicted by the GHM model in which "unified (coordinated) decision making is not attempted"(Williamson, 2002a: p. 442) is a "strange" prediction and "a very unusually condition"(Williamson, 2000: p. 606)

Finally, while TCE is often described as "an empirical success story" (Williamson, 1996a: p. 55) backing up by a huge empirical literature, the GHM model (and more generally, the new property rights theory, PRT) faces several notable challenges in deriving and testing its empirical predications[19]. In particular, many authors (Whinston, 2001, 2003; Woodruff, 2002) noted that the predicted patterns of integration in the transactions cost framework depend on the level of specificity; whereas in the GHM model, integrations depend instead on marginal specificity, and an increased specificity may result in less integration because specificity can increase

[18] Regarding the "common knowledge" assumption, Williamson (2002a: p. 440) once observed that, given bounded rationality, "the readiness with which common knowledge of payoffs is invoked is deeply problematic".

[19] Apart from the challenges described below, it is also widely noted (Holmstrom & Roberts 1998; Holmstrom & Tiorle, 1989; Whinston 2003) that specific predictions of the GHM model depend critically on subtle details of the model. The only general insight is that asset ownership affects incentive to invest in non-contractible investment, so that *ownership should be assigned to the party whose investment in non-contractible relationship specific investment (mainly human capital) contributes most to the value of the relationship*.

the costs as well as the benefits of integration. As the margins are hard to observe (especially when they are the marginal effects of non-contractible actions on non-contractible payoffs), the prediction of the property-rights theory could hardly be tested directly[20] (Whinston, 2001) or is even "nearly untestable" (Williamson, 2002a: p. 442). Moreover, Whinston also indicated that although there is considerable evidence in support of the TCE, "the existing empirical evidence that is supportive of the TCE sheds little light on the empirical relevance of the PRT" (Whinston, 2003: p. 20), and the rich set of predictions offered by the PRT deserves empirical scrutiny in future research. In fact, many of the subsequent empirical studies have tried to conduct a horserace test between these two approaches when they make different predictions[21], by which limited empirical evidence (Acemoglu, Griffith, Aghion, & Zilibotti, 2010; Baker & Hubbard, 2003, 2004; Woodruff, 2002) has been found to be supportive of the property right approach. Nevertheless, more solid empirical studies are much needed.

Summing up, as Williamson (2000) himself has emphasized and many others concurred (Gibbons, 2005; Holmstrom & Roberts, 1998; Whinston, 2001, 2003), although the GHM model shares with Williamson's TCE many commonalities, it is nonetheless a different theory, not simply a formalization of TCE, or at best a biased formalization. Ultimately, the two theories as the respective *outgrowth of two very different research traditions.*

3.4 Conclusions

This chapter is devoted to a review of Williamson's Transaction cost economics, and in particular, his theory of the firm, which is now the dominant theory in this field.

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[20] Nine years after the first formal model was published, Hart himself remarked that "[U]nfortunately, there has to date been no formal test of the property rights approach..." (Hart 1995: p. 49).

[21] Generally speaking, predictions that differentiate the transactions cost and property rights theories have do with the ***direction*** of integration, and the ***costs of integration*** associated with the ***reduced incentives*** of the partied being integrated (the employee) to invest in relationship specific ***human*** capital (Hart, 2011).

For example, using plant-level data for the UK manufacturing sector, Acemoglu *et al.* (2010) examine the effects of the producer's and the supplier's respective technology intensity (as proxies for relationship-specific investment) on the probability of backward integration (producer integrate supplier). In the TCE framework, integration is un-directional, so the technology intensities of both industries are predicted to be positively associated with backward integration. While in the GHM framework, it is suggested that backward integration increases the producer's incentive to invest in non-contractible asset but it also reduces the supplier's incentive to invest. Therefore, it is predicted that the technology intensity of the producer and the supplier would have opposite effects on the likelihood of backward integration. In this sample, Acemoglu et al. (2010) finds that, consistent with the prediction of the GHMs models, a higher technology intensity of the downstream producer increases the probability of backward integration, whereas a higher technology intensity of upstream supplier reduces that probability.

The chapter consists of three main parts. In part one, we summarize the basic elements (or what he calls "precepts") of Williamson's approach. Specifically, these basic elements include, among others: (1) To take transaction as the basic unit of analysis and to adopt the lens of contract; (2) To pose the problem of economic organization as a micro-analytic problem of comparative contracting (Williamson, 2002b, 2003b) and to implement the transaction cost economizing logic; (3) The comparative contractual approach to the issue of economic organization in general and to the theory of the firm in particular, is implemented through a series of key operationalizing moves (Williamson, 1979, 1985, 1991)—i.e., to identify the behavioural assumptions; to dimesionalize the few critical attributes that are responsible for differential transaction costs under alternative modes of governance; to name and explain the few critical attributes with respect to which governance structures differ and then to describe them as discrete structural alternatives; and to work out the logic of efficient alignment; (4) In the contractual world of transaction cost economics, bounded rationality and opportunism have been identified as the two crucial behavioural assumptions for setting up the analysis (Williamson, 1975, 1985b); (5) Asset specificity, uncertainty, and frequency have been identified as the few critical dimensions by which the magnitude of the contractual hazards vary systematically. In Williamson's view, the most critical dimension is that of asset specificity since the governance ramifications of the other two dimensions can not be fully and independently appreciated until joined with asset specificity (Williamson, 1979: p. 239); (6) Transaction cost economics holds that the few generic modes of governance—market, hybrid, hierarchy etc.—differ from each other by a syndrome of internally consistent attributes to which different adaptive strengths and weaknesses accrue. These attributes, as identified by Williamson (1991), are incentive intensity, administrative controls, and contract law regime; (7) Transaction cost economics places a strong emphasis on deriving refutable implications and submitting them to data. It owes much of its predictive content to the "discriminating alignment hypothesis" (Williamson, 1991) which holds that transactions, which differ in their attributes, are aligned with governance structures, which differ in their costs and competencies to implement autonomous and coordinated adaptations, in a discriminating way; (8) Transaction cost economics is much concerned with public policy ramifications, and it introduces the "remediableness criterion" as the efficiency criterion for public-policy analysis.

In part two, we discuss in detail the basic framework of Williamson's theory to the boundary determination of the firm. In particular, we focus on three key aspects of his theory, namely, the dimensionalization of transactions, the dimensionalization of governance structures, and the discriminating alignment.

As observed by Williamson (2000, 2010b), transaction cost economics has undergone a natural progression from informal, pre-formal, to semiformal, and finally to full formalization. The paper by Grossman and Hart (1986), and the follow-on paper by Hart and Moore (1990) (known as the GHM model)—which started the (new) "property right theory" literature (N. J. Foss, 2010b; J.T. Mahoney, 2005)—have been widely viewed as path-breaking works in this regard.

In part three, we review and domonstrate the basic insights of the GHM model. We show that although the GHM model shares with Williamson's TCE an appreciation for contractual incompleteness and an emphasis on relation-specific investment, there are fundamental differences between these two approaches. Given these differences, GHM model is at best a partial formalization of Williamson's theory; and indeed, the two approaches are better understood as two distinct theories.

Note

[1] When the phase was first coined (Williamson, 1975), the word "new" is intentionally used to differentiate itself from the "*Original Institutional Economics*"(OIE), the body of literature associated with Thorstein Veblen, John R. Commons, Wesley C. Mitchell, Clarence Ayres and their followers. Although *New Institutional Economics* shares many common research interests with their earlier counterpart (e.g.., both of them are interested in the social, economic and political institutions that govern everyday life and they both embrace the proposition that ***institution matters***) and indeed follow some of the research traditions established by their predecessors (e.g., taking transaction as the basic unit of analysis; viewing economics as the science regarding the realization of "mutuality of advantage from voluntary exchange" through the ***lens of contract*** rather than regarding efficient allocations of resources among competing ends through the ***lens of choice***), they nevertheless disagree with the methodology of original institutional economics in a fundamental sense.

Coase's (1984, p. 230) criticism on the part of traditional institutionalists is particularly pertinent. He observed that 'without a theory they had nothing to pass on except a mass of descriptive material waiting for a theory, or a fire'. To put it more explicitly, one of the major weaknesses of the original institutional economics is that it has placed an undue emphasis on empirical observation over deductive reasoning. In a sense, it is anti-theoretical (Coase, 1998). In addition, Original Institutional economics (OIE) maintains a long-standing tradition of methodological holism (Hodgson, 1993; Rutheford, 1994; for a clear definition of methodological individualism/holism, see Samuels, 1972)—they use some collective theoretical construct (e.g., culture, norm, and formal institution) to explain economic phenomena, however, by taking institutions as *explanans* rather than *explananda*, institution itself has been left out of analysis.

Within NIE, two distinct branches of research could be identified (Davis & North, 1971; Williamson, 2002a, 2002b). The first is concerned with "***institutional environment***" or "***public ordering***" while the second, by contrast, is concerned with ***"institutional arrangement"*** or "***private ordering***".

Institutional environment (Davis & North, 1971; North, 1990), are the background constraints, or 'rules of the game' (North, 1990, p4) that guide individuals' behaviour. Such rules can be both formal, explicit rules (constitutions, laws, property rights) and informal, often implicit rules (social conventions, norms). In the view of the new Institutionalist, these background rules are the product of—and thus could be explained in terms of—the goals, beliefs, actions and choices of individual actors. However, the emergence of these rules, more often than not, is spontaneous, they are the result of "human action but not of human design" through an evolutionary social selection process (Hayek, 1967, 1973).

Institutional arrangements or private ordering, by contrast, are the "play of the game" which "entails efforts by the immediate parties to a transaction to align incentive and to craft governance structures that are better attuned to their exchange needs" (Williamson, 2002b: p.172). According to Williamson (2002b), private ordering, in turns, splits into two branches: one branch concentrates on front-end incentive alignment (mechanism design, formal agency theory, formal property right literatures concern themselves mainly with this issue), whiles the other, where Williamson locate himself, features the governance of ongoing contractual relation (contract implementation). More specifically, the few generic governance structures (1985, 1996b), defined by "a syndrome of internally consistent attributes to which different adaptive strengths and weakness arc cure" (2003, p. 925), are viewed as the means "by which to infuse order, thereby to mitigate conflict and realize mutual gains" (2003, p. 921). Business firms, long-term contracts, public bureaucracies, non-profit organizations and other contractual agreements—delicate as they might be—are all examples of institutional arrangements.

For a review on the relationship between "new" and "old" institutional economics, see Langlois (1989) and Hodgson (1993); For a review on the essential characteristics of the NIE and how it differs from neo-classical theory, see North (1993); For an overview of the field, see Klein (1999).

Chapter 4: The Problem-Solving Perspective

4.1 Introduction

In the resource-based view (RBV) and knowledge-based view (KBV) literature, knowledge creation has long been identified as the key driver for sustainable competitive advantage of the firm (DeCarolis & Deeds, 1999; Grant, 1996a, 1996b; Nelson & Winter, 1982; Winter & Szulanski, 2001). However, the mechanisms by which the knowledge creation process is governed have been largely underexplored. Theories of economic organization have concerned themselves more with the exchange, transfer, application and protection of knowledge, while rather limited attention has been paid to the organization and governance of knowledge creation (N. J. Foss, 2007, 2012). Put differently, in the resource-based and knowledge-based view literature, or more generally, in the field of strategic management and economic organization, the vast majority of research has focused on value protection (e.g., Oxley, 1997) and value capture (e.g., G. P. Pisano & Teece, 2007; Teece, 1998), while the problem of value creation has, to a large extent, been relatively underexplored (Bowman & Ambrosini, 2000; Heiman & Hurmelinna-Laukkanen, 2010; Nickerson et al., 2007; Pitelis, 2009).

The failure to address the problem of knowledge creation has been attributed to the choice of inappropriate unit of analysis (Heiman et al., 2009; Nickerson et al., 2007). For example, in the TCE, the question is—given an identified exchange, how to organize it efficiently to economize the transaction costs (Williamson, 1999b). While in most of the KBV literature, the question to be put instead is—given an firm's pre-existing strength and weakness in knowledge bases and capabilities, how to organize an identified exchange to capture value? In both cases, it is implicitly assumed that value-creating knowledge is already in hand and the only concern is then how to organize the exploitation of the knowledge to better capture the value from it. If, however, the problem is how to organize knowledge creation or how to govern the value creation process, transaction is apparently not an appropriate unit of analysis.

The problem-solving perspective (PSP) suggests that problem is the useful unit of analysis upon which an organization theory of value creation can be build (Heiman et al., 2009; Leiblein & Macher, 2009; Macher, 2006; Nickerson et al., 2007; Nickerson, Yen, & Mahoney, 2012; Nickerson & Zenger, 2004). Specifically, they argue that the key task for the manager/entrepreneur is to identify a valuable problem and then, based on the attributes of the problem, to organize an efficient solution search. The firm, by organizing problem finding and solving efficiently, creates value.

Relatedly, in light of the exploitation/exploration distinction made by March (1991), the problem-solving perspective is characterized by a distinctive exploration orientation, whereas in the traditional approaches, the exploitation logic dominates (Gray, 2001; Heiman & Hurmelinna-Laukkanen, 2010). Specifically, by exploring an economizing logic of managerial choice to maximize expected values of problem finding and problem solving, the approach tries to work out a discriminating alignment between the problem-solving (knowledge creating) activities with different attributes on the one hand, and the few generic governance structures on the other. Ultimately, the research questions in this perspective reduce to (Nickerson et al., 2012) (1) how to identify valuable problems and opportunities, the resolution of which enables the firm to create and capture value; (2) how to effectively organize—based on the attributes of the problem—the solution search for a chosen problem; and (3) once the solution for a chosen problem is found, how to efficiently implement the solution to create and capture value?

Given that our research is primary concerned with the boundary determination of the firm, our review will focus more narrowly on the issue of problem solving[1].

In many aspects, the problem-finding and problem-solving perspective follows the method of “discrete structural analysis” developed by Williamson (1991). Although it adopts a different unit of analysis from TCE, the problem solving perspective applies similarly the logic of “discriminating alignment” (Williamson, 1991) in evaluating the relative costs and competencies of alternative governance mechanisms in solving problems with different attributes. Specifically, based on Simon’s work on problem solving (1962, 1973), Kauffman’s (1993) work on the NK modeling, and Kogut and Zander’s contributions to the knowledge-based view of the firm (1988; 1992, 1993, 1995), a few problem attributes (such as problem complexity, decomposability, and problem structure) and knowledge characteristics (such as knowledge tacitness and social distribution) have been identified as being crucial in understanding the impediments to problem-solving activities (knowledge-transfer and knowledge-formation hazards) (Brusoni et al., 2007; Heiman & Nickerson, 2002, 2004; Macher, 2006; Nickerson & Zenger, 2004). Furthermore, it is also identified

[1] For those who interested in the issue of problem finding, please refer to Baer, Dirks, & Nickerson (2012), Hurmelinna-Laukkanen & Heiman (2012) and relevant sections in the following few papers (Heiman et al., 2009; Nickerson et al., 2007; Nickerson et al., 2012). It seems to the current author that compared with the issue of problem-solving, the issue of problem finding (identification, formulation) is even underexplored.

that as far as the costs and competencies for implementing solution searches for different types of problem are concerned (by mitigating knowledge formation hazards and other impediments), the few generic organizational modes differ with respect to the dimensions of incentive intensity, communication channels, and dispute resolution regime (Heiman & Nickerson, 2002, 2004; Leiblein et al., 2009; Nickerson & Zenger, 2004). Finally, the problem-solving perspective works out the match between these problem/knowledge attributes and the few generic organization modes in an economizing manner that realizes efficient solution search and maximizes expected values of problem solving (Heiman & Nickerson, 2002; Leiblein & Macher, 2009; Macher, 2006; Nickerson & Zenger, 2004).

It should be emphasized again that this chapter focuses on the issue of problem-solving and it is only meant to present the most critical new insights, to demonstrate its substantial potential, to identify the gaps in the existing research and to sketch out some directions for future developing this emerging perspective.

4.2 Value Creation, Exploration and Discovery

Traditionally, the central research theme in strategic management is to identify the sources of a firm's sustainable competitive advantage (Barney, 1991). More recently, the theme has been recast in a more dynamic manner as "how can a firm create and capture value?" (Nickerson et al., 2007).

As mentioned above, however, the vast majority of the research in the field of strategic management and economic organization tends to focus on value capture rather than value creation. Specifically, in the industry analysis approach associated with Michael Porter (1980, 1985), and the game-theoretic new industrial organization approach (Kreps, 1990; Shapiro, 1989; Tirole, 1988), strategy is largely an exercise of deploying given resources to a product market to secure a favourable market position, typically through entry deterrence, price-discrimination, product differentiation, etc. As pointed out by Foss and Mahnke (2000), in these two approaches, strategy is a matter of reaping *monopoly rents* out of "fixed factors over the planning horizon"(Caves, 1984: p. 128). While in the perspective of transaction cost economics, value is protected and captured mainly by economizing on transaction costs (Nickerson, 1997; Oxley, 1997; Teece, 1986; Williamson, 1975, 1985b).

The resource-based view seems to be more concerned with value creation (e.g., Prahalad & Hamel, 1990). Specifically, the resource-based view switches the focus from the external environment to internal resources and capabilities (N. J. Foss, 1997;

Spanos & Lioukas, 2001), it contends that firm strategy is "*to account for the creation, maintenance and renewal of competitive advantage in terms of the resource side of firms*" (N. J. Foss, 1998: p. 135). In Barney's (1991) formulation, sustainable competitive advantage derives from the resources and capabilities a firm controls that are *valuable, rare, imperfectly imitable, and not substitutable*. In Peteraf's (1993) slightly different formulation, the cornerstones of sustainable competitive advantage are *heterogeneity of resources*, *imperfect mobility*, *ex post limits to competition* and *ex ante limits to competition*. Overall, the basic insights of the resource-based view indicate that: (1) systematic differences across firms with respect to the resources they control are necessary for implementing strategies—i.e., resource heterogeneity, which leads to efficiency differences and therefore "*Ricardian rents*" (Peteraf, 1993), is a necessary condition for competitive advantage, and; (2) as results of the remaining three other conditions (each being a sufficient condition for sustainable competitive advantage), the inter-firm efficiency differences are relatively stable[2], meaning that the rents are sustainable and; (3) systematic differences in firms' resource endowments thus cause persistent performance differences. In this view, strategy is mainly to look "within the enterprise and down to the factor market conditions that the enterprise must contend with, to search for some possible causes of sustainable competitive advantages" (Peteraf & Barney, 2003), and in particular, to access and exploit resources that generate Ricardian rents (Barney, 1986, 1991; Dierickx & Cool, 1989; Peteraf, 1993).

As it is clear now, even in the resource-based view, there is no clear conceptual model of endogenous value creation (N. J. Foss, 1998), and value creation is largely assumed. For instance, with a few exceptions[3] (e.g., Dierickx & Cool, 1989; Montgomery & Wernerfelt, 1988; Wernerfelt, 1984), the resource-based view offers few recommendations on how to organize value creation in a continuous and sustainable fashion, nor does it provide specific predictions on which asset or asset combinations are likely to be valuable (Heiman et al., 2009).

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[2] "[E]x ante barriers" means that factor markets do not appropriate all of the rents from a resource, because the resources are acquired at a price below their discounted net present value in order to yield rents (Barney, 1986; Demsetz, 1973); "ex post barriers" means it is difficult or impossible for competitors to imitate or substitute rent-yielding resources, therefore the rent differential is not eliminated through product market competition (Dierickx & Cool, 1989); "imperfect mobility" means, due to the existence of factor market imperfections which limit the extent by which a resource could be mobilized at competitive terms (so-called mobility barrier or isolating mechanism) (Caves & Ghemawat, 1992; Lippman & Rumelt, 1982; Rumelt, 1984), not all of the rent differential is eliminated through factor market competition.

[3] It seems to the author that in the RBV literature, research on diversification provides more insights on value creation than other research themes.

On a deeper level, it has been argued that the relative inability of the resource-based view in addressing the problem of value creation can be attributed to the equilibrium thinking[4] deeply rooted in the majority[5] of this literature (N. J. Foss, 2000a, 2003c; Mahoney & Pandian, 1992). Specifically, in developing this view, many RBV theorists (e.g., Jay Barney and Richard Rumelt) explicitly draw on UCLA-Chicago approach industrial organization theory (Demsetz, 1973, 1974, 1982, 1989). As a consequence, in the resource-based view, sustainable competitive advantage is generally understood as a property of equilibrium[6]—a competitive equilibrium in which firms earn efficiency rents mainly arising from costly-to-imitate resources. Given its theoretic foundations, it is not a surprise that resource-based view has provided fewer insights on more dynamic issues such as learning, value creation, opportunity discoveries and innovations[7].

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[4] Porter's industry analysis approach and the game-theoretic new industrial organization approach to strategy are also based on some variants of mainstream, equilibrium oriented economic theory. Specifically, the theoretic foundations for these two approaches are Bain-type industrial organization theory and game theory, respectively.

[5] Resource-based view has often been traced back to the seminal work of Edith Penrose (1959) who explicitly rejected equilibrium theories of the firm (Conner, 1991; Mahoney & Pandian, 1992). Given that Penrose is the first to argue systematically for the importance of resource heterogeneity for strategic analysis, and that RBV places its analysis on the cornerstone assumption of resource heterogeneity (Peteraf, 1993), it could be argued that RBV is fundamentally Penrosian in its emphasis on resource heterogeneity (Foss & Foss, 2004). However, it other aspects, RBV, especially in its pure form (c.f. note **8**), received far more influence from Chicago-UCLA approach to industrial organization than Penrose's theory (Foss, 2000, 2003). In the "pure" version RBV theory, heterogeneity is explained as an endogenous equilibrium outcome of isolating mechanisms and uncertain imitability, whereas in Penrose's theory, heterogeneity is viewed as an outcome of a disequilibrium process of Schumpeterian competition and entrepreneurial discovery (Mahoney & Pandian, 1992).

That being said, however, for the part of RBV literature that deals with the analysis of diversification (Teece, 1980, 1982; Wernerfelt, 1984; Montgomery & Wernerfelt, 1988; Silverman, 1999), the Penrosian influence is more apparent.

[6] For example, Barney(1991: p. 102) defined sustainable competitive advantage in such a way that:

"[A] firm is said to have a *competitive advantage* when it is implementing a value creating strategy not simultaneously being implemented by any current or potential competitors. A firm is said to have a *sustained competitive advantage* when it is implementing a value creating strategy not simultaneously being implemented by any current or potential competitors and when these other firms are unable to duplicate the benefits of this strategy. (1991: p. 102; emphasis in original).

In other words, sustained competitive advantage is defined as the advantage that lasts after all attempts at imitation cease, so zero imitation equilibrium is utilized as a benchmark to understand sustained competitive advantage.

[7] By contrast, in the market processes literature associated with Austrian and evolutionary economics (Hayek, 1948; Kirzner, 1973; Loasby, 1976; Penrose, 1959; Schumpeter, 1934), competition is described as a process of continuous disequilibrium (or at least a process of evolutionary selection) driven by discoveries for new profits opportunities (Kirzner, 1973) and novel resource combinations (Schumpeter, 1934). In this view, competition becomes a matter of learning and exploration in an fundamentally uncertain world, and competitive advantage derives from the (subjective) perception (Loasby, 1976; Penrose, 1959) and discovery of novel combination and recombination of existing resources that create new value (Kirzner, 1973; Schumpeter, 1934; Penrose, 1959), and the coordination of partially tacit knowledge and collective learning (Hayek, 1948).

Related to the above point, it is also identified that the resource-based view (RBV) in its "pure" form[8] is mainly a theory of strategy rather than a theory of economic organization (K. Foss & Foss, 2004), since it tells us very little about the organization of the firm, especially about how the process of value creation is organized. Surely, the capabilities and the knowledge-based view literature have contributed valuable new insights on the boundary determination of the firm, but that is achieved mainly by following the exploitation logic. For example, in the capabilities view (Kogut, 1988a; Kogut & Zander, 1992, 1993; Langlois, 1988, 1992; Langlois & Foss, 1999; Langlois & Robertson, 1989), it is argued that productive knowledge is often tacit and socially distributed—that is, knowledge required to perform a productive activity is often hard to articulate and not possessed by any single mind; instead, it is distributed among a group of interacting agents, emerging from the aggregation of the tacit knowledge elements of these interacting individuals in the firm-specific context of carrying out a multi-person productive task. Given these characteristics of productive knowledge, it is argued that firms tend to internalize the utilization of tacit and socially distributed knowledge as internal replication economizes the costs associated with the transmission of such knowledge which are independent of opportunism.

Obviously, these insights are mainly about how to organize the *exploitation* of tacit and socially distributed knowledge—given the differential costs of intra-and inter-firm knowledge transmission—to better *capture the value*. But this literature doesn't tell us much about how to organize the "voyage of *exploration* into the unknown" (Hayek, 1948/1996) by discovering novel knowledge/resource combinations that create new value[9].

Our point can be better illustrated with reference to the production function view.

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[8] The term is used by the authors (K. Foss & Foss, 2004) to describe a variant of the RBV which is exemplified by Barney (1991), Peteraf (1993) and which is to be distinguished from other variants of RBV such as the dynamic capabilities and the competence approach (Prahalad & Hamel, 1990; Teece & Pisano, 1994).

[9] One of the few notable exceptions is Kogut and Zander (1992), who introduce the concept of the "combinative capability" and conceptualize knowledge creation as products of a firm's combinative capabilities which generate new knowledge applications by combining existing knowledge sets, often realized through localized search and guided by a stable set of firm-specific heuristics. While the notion of "combinative capability" and their discussions on knowledge creation are clearly evocative of an exploration logic or even suggestive of the basic ingredients of the problem-solving approach (e.g., knowledge combination, problem identification and problem-solving, solution search, search heuristics, the dimension of complexity), Kogut and Zander (1992) end up concluding that firms exist because they provide a social community of voluntaristic action structured by a set of higher order (not reducible to individuals) organizing principles that facilitate the internal transfer of knowledge, and they stop short of articulating what these higher order organizing principles for value creation and problem solving really are.

In the neoclassical perfect competition theory, the firm is described as a production function that convert input into output (Arrow & Hahn, 1971). In this view, input is homogeneous, technological efficiency is always ascertained, each party has perfect and complete information; as a results, all firms face the same exogenously given production function. Collectively, the firms' ambitions to maximize profits yield a market equilibrium of zero economic returns to each firm.

Although it is generally recognized that the choice of organization modes depends on the sum of production costs and transaction costs (Riordan & Williamson, 1985), transaction costs economics focus exclusively on the later category of costs. Specifically, it adopts a pragmatic methodology by holding production technology constant and exogenously determined, and looking only at transaction costs (Williamson, 1985b: p.88). In this view, the production possibility frontier (PPF) for any specific firm is given, and the differences in firm efficiency[10] are explained by the extent to which transaction costs hinder the firm from reaching its production possibility frontier.

By contrast, in the pure-form resource-based view, the firm is often described as a bundle of heterogeneous resources. Differences in production efficiency are taken as its theoretic premise, and such differences are explained mainly in terms of a firm's preferential access to heterogeneous inputs (resources) and the inherent efficiencies of the resources a firm controls. In short, in the pure-form resource-based view, inter-firm differences in production costs are exogenously determined, and the production possibility frontier for a specific firm is at least known, if not given.

In the capabilities and knowledge-based view, the production function becomes partially endogenous. For example, due to the differential costs of intra-firm and inter-firm knowledge transmission, different firms would have different production efficiencies (i.e., they would face different production possibility frontiers) even applying the same technology. More generally, given that a firm's 'organizing technology' plays an important role in the transformation of inputs into outputs, even if two firms have access to similar inputs and technology, inter-firm performance differences can still exist due to differences in organizing skills, activity portfolios, existing knowledge bases and learning abilities (Madhok, 2002). However, even in

[10] To be more exact, in the transaction cost economics, inter-firm differences in production costs could be allowed (Riordan & Williamson, 1985; Williamson, 1988), but primarily in the form of (a) economies of scale that distinguish external suppliers from in-house production (markets enjoy advantages by aggregating the demands of many buyers, thereby realizing economics or scale or scope) and (b) differences in technology (specialized vs. generic). In both cases, technology is still held constant (Madhok, 2002)

this view, novelties and surprises play no role as the potential frontier of a firm's production possibility is fundamentally known. What the firm can do, is to push closer to this potential by squeezing every drop of value out of its existing resources and knowledge; and what is still lacking is a clear-cut logic on how to organize the "exploration into unknown" by discovering novel resource combinations that push outward the production possibility frontier.

To sum up the above discussion, existing literature on strategic management is primarily concerned with value capture activities, while the vital role of value creation, to a large extent, is neglected. In all of the aforementioned perspectives, it is often assumed that value pre-exists in the firm, and the central challenge is to secure a portion of the created value, in excess of costs, to be captured by the firm. Some more dynamic views of strategic management (e.g., the capabilities view, the knowledge-based view) acknowledge the importance of value creation, but these strands of literature fail to provide more insights on the actual details of value creation. Similar challenges exist for the economic organization literature in that most of the literature tends to follow the exploitation logic, whereas how a firm organizes its exploration for a higher production possibility frontier is basically unclear.

Thus, fundamentally lacking in the strategic management and economics of organization literature is an in-depth understanding of the mechanisms by which firms create value in a deliberate and continuous fashion, and the mechanisms by which firms generate valuable new knowledge. Apparently, discovering new sources of value and rents is more critical to the maintenance and renewal of a firm's competitive advantage than focusing narrowly on value capture and defending its competitive position.

Apart from being a strategic issue of paramount importance, creating value, and doing so in a sustainable and continuous fashion is a organizational issue as well (Heiman et al., 2009). For instance, persistently creating new value requires a better understanding of: (a) how a firm organizes the exploration into unknown territory, given its existing capabilities to assemble knowledge to solve problems, by discovering novel resource/knowledge combinations that push outward the production possibility frontier; and (b) once a valuable solution is found, how a firm organizes the implementation of the solution to yield substantial economic value.

As we will see later, the problem solving/problem finding perspective offers a superior framework for addressing the issues of value creation and the organization of discovery. Specifically, the key question for problem finding is (Baer, Dirks, & Nickerson, 2012; Hurmelinna-Laukkanen & Heiman, 2012): given a firm's existing capabilities to assemble knowledge sets to solve the problem, how can a firm organize a search to identify a valuable problem whose resolution can be expected to generate significant value? Once a valuable problem is identified, the next task is then to search for a solution to this problem. In this regard, the key question is: how can a firm organize an efficient search for high value solutions to an identified problem? The problem-solving perspective (Brusoni et al., 2007; Heiman et al., 2009; Leiblein & Macher, 2009; Macher, 2006; Macher & Boerner, 2011; Nickerson & Zenger, 2004) argues that the efficient solution search depends on the structure, complexity and decomposability of the problem, the characteristics of the relevant knowledge, as well as the relative efficacy of various governance mechanisms in implementing different search methods (strategies) and in alleviating knowledge-formation hazards. Specifically, some problems can be solved through the combination of independent, modular, trial-and-error searches which require little organizational control. Other problems require coordinated or heuristic search which necessitates knowledge sharing across agents; for such problems, various forms of hierarchy or collaborative arrangement are better able to efficiently manage the attendant knowledge-formation hazards (Heiman et al., 2009; Leiblein & Macher, 2009; Nickerson & Zenger, 2004).

Below, we will review in detail the literature on the problem-solving perspective. The review will be divided in two sections. In section 4.3, we review the background literature on the NK Model and its application in the fields of strategic management and economics of organization. This stream of literature is widely recognized (Leiblein & Macher, 2009; Nickerson & Zenger, 2004) as a source of theoretic inspiration to the problem solving perspective. In section 4.4, we review the main body of literature on the problem solving perspective.

4.3 The NK Model

Although it is generally acknowledged that NK modelling literature is a source of theoretical inspiration to the problem solving perspective, this literature is probably less familiar to most economists working with the theory of the firm. What are the basic insights of this literature? How could these insights be linked to the problem solving perspective? These topics are less reviewed systematically in the problem solving perspective literature. We fill this gap by introducing the basic elements and methods of the NK simulation, highlighting its advantages and shortcomings, and presenting the basic insights of recent economic and strategy applications of the NK model.

4.3.1 The NK Model: General Background

The problem-solving approach to the boundary determination of the firm first articulated by Nickerson and Zenger (2004) seeks explicitly to combine transaction cost economics (Williamson, 1975, 1985b, 1996b), complexity theory (Simon, 1962; Kauffman, 1995) and *knowledge-based view* of the firm (Conner, 1991; Conner & Prahalad, 1996; Demsetz, 1988; N. J. Foss, 1996a, 1996b; Kogut & Zander, 1992, 1993, 1996) in explaining how the choice of alternative organizational forms influences the efficient creation of valuable knowledge.

In particular, in this approach, the conceptualization of problem and solution search draws directly from Simon's (1962, 1969, 1973) work on complex systems and Kauffman's (1993) work on NK modelling.

Simon conceptualized a complex system as one "made up of a large number of parts that interact in a non-simple way" (H. A. Simon, 1962). He identified the number of system components, degree of interaction between system components, decomposability and system structure as the few critical dimensions to describe the complexity of a system. On this basis, Simon (1969) also described the complexity of a technological problem in terms of the combinatorial complexity of its design choices, and he suggested that the relative efficiency of different solution search methods depends in part on the complexity of the problem.

In the field of biology, biologists face similar problems when studying the evolutionary properties of complex biological systems (Kauffman, 1993; Kauffman & Levin, 1987). Specifically, in biology, one distinguishes between the genotype and the phenotype of an organism. At the level of the genotype, gene mutations lead to new variants in a population, whereas at the level of the phenotype—which is the embodiment of traits that account for an organism's fitness—natural selection operates in terms of differential rates of reproduction. Interdependencies among genes imply a complex relation between an organism's genotype and an organism's phenotype. To be more exact, a gene does not simply translate into a particular trait, it also operates in conjunction with other genes by regulating the function of other genes. Accordingly, a mutation in one gene may not only change the functional contribution of the mutated gene to the entire phenotype, it can also affect the functional contributions of other interrelated genes to the phenotype (Frenken, 2006b). As a consequence, a mutation in a single gene may have both positive effects on some traits and negative effects on some other, which jointly determine an organism's fitness (Kauffman, 1993).

To analytically model the evolution of complex biological organisms, in which the complexity stems from the interdependency in the functioning of genes, Stuart Kauffman, a medical doctor associated with the Santa Fe Institute, developed the NK-model (Kauffman, 1993), in which the interdependence is linked to the topography of "fitness landscapes" (Wright, 1931), and the evolution is modelled as a process of searching for higher fitness values on the landscape, like a climber trying to navigate a way up a mountain range (Sorenson, 2002). In his book, *The Origins of Order: Self-Organization and Selection in Evolution* (1993), Kauffman describes the NK-model in detail and demonstrates its applicability to and implications for a variety of biological problems

Although Kauffman's NK model was originally conceived as a means of simulating, through parameter variation, the evolution of biological systems, it was soon found that it can be applied more generally to model other complex systems in which the degree of complexity depends on the interaction among elements. The NK model then arises as a rather standard tool for the formal representation of complexity (Richard & Larry, 2011). In the fields of economics and strategy research, researchers are concerned similarly with the type of complexity that arises from the interdependent working of the constituting elements in complex economic or technological systems (e.g., Rosenberg, 1969; H. A. Simon, 1969). This similarity provides the basis for transferring the NK model from the realm of biology to the realm of economics and strategy (Frenken, Marengo, & Valente, 1999; Kauffman, 1988; Kauffman, Lobo, & Macready, 2000; Levinthal, 1997), and the formal structure of the NK model has been proved a useful tool for generating insights in the domain of the technological innovation, firm strategy and organisation (Frenken, 2006c).

4.3.2 The NK Model: Some General Descriptions

The NK model consists of two main components—the NK fitness landscape and the agent(s) that searches the landscape, the characteristics of both being controlled by model parameters (Ganco & Hoetker, 2009). The parameters *N* and *K* characterize the fitness landscape over which the agent(s) search for better payoffs, while the searching behaviour of the agent(s) is controlled by setting the rules by which the agent(s) performs the search over the landscape. In the original setting of *NK* model (Kauffman, 1993), the parameter *N* stands for the number of "alleles" in the genome that can be either turned on or off, while K defines the density of "epistatic connections" between individual alleles. In the perspective of theory of complex systems (H. A. Simon, 1969), N defines the number of elements that make up the system, whereas K describes the functional interdependencies between the elements of the system. In the economics and management applications[11], the notion of "alleles" is replaced by decisions (or design choices) and "epistasis" by interdependence between decision/design elements (Ganco & Hoetker, 2009). N then represents the number of decisions or the design choices to be made, (e.g., decisions regarding firm strategy, product design, problem solving, etc.) and K controls how connected these decisions are. The notion of search in the original *NK* model represents the process of population-level genetic mutation, whereas in the economics and management applications, the notion of genetic mutation has been replaced by adaptive and purposive search behavior of the agent(s) though it may be complemented by population level dynamics driven by selection (Levinthal, 1997); and the agent(s) making the decisions can be operationalized at the different levels (Ganco & Hoetker, 2009): individual (Gavetti and Levinthal, 2000), sets of individuals (Rivkin and Siggelkow, 2003) or an entire organization (Levinthal, 1997).

4.3.3 The NK model: A Formal Presentation

In the NK model, a system is represented as a string of elements linked together by a web of interdependencies (referred to as "epistatic" relations in population genetics) which maps into a rugged fitness landscape that determines the fitness level of the configuration of elements (Dosi, Faillo, Marengo, & Moschella, 2011).

More formally, a system is described by a string of N elements that make up the system. For each element n (n=1,2,…, N), there exist A_n possible states[12] (alleles) which can be labelled by integers "0", "1", "2", "3", etc. Each string s is described by alleles $s_1 s_2 \ldots s_N$, and s is part of possibility set S, i.e.,:

$$s \in S \; ; \; s = s_1 s_2 \ldots s_N \; ; \; s_n \in \{ 0, 1, \ldots, A_n - 1 \} \tag{4.3.1}$$

This N-dimensional possibility set of all possible configurations (strings) of the system S is called the "possibility space of the system" (Luigi Marengo et al., 2000), or when the system under concern is a technology, it is called the "design space" of a

[11] For a detailed discussion on the technical issues relevant to the applications of NK modelling in strategy-related questions, see Ganco & Hoetker (2009).

[12] For the sake of simplicity, in most applications the number of states is reduced to two, i.e., $A_n \in \{0, 1\}$.

technology (Bradshaw, 1992; Frenken, 2006c). The size of the possibility space of the system *S* is given by:

$$S = A_1 \cdot A_2 \cdot \ldots \cdot A_N = \prod_{n=1}^{N} A_n \qquad (4.3.2)$$

In the original *NK* model, interdependencies between the functioning of elements in a complex system are called "epistatic relations" (Kauffman, 1993: p. 41). An epistatic relation from element *i* to another element *j* implies that when the state (allele) of the element *i* changes, the change affects both the functioning of element *i* and the functioning of element *j* that element *i* epistatically affects. In a technological system, the ensemble of epistatic relations within a system is called a system's internal structure (H. A. Simon, 1969) or architecture (Henderson & Clark, 1990).

The architecture of a system can be illustrated by the following example adapted from Frenken (2001b).

A particular vehicle technology can be described by the following three elements and their respective alleles:

$n=1$ (A_1= 2): engine element with three alleles	gasoline(0) or electric (1)
$n=2$ (A_2= 2): suspension element with two alleles	spring (0) or hydraulic (1)
$n=3$ (A_3 = 2): brake element with two alleles	block (0) or disc (1)

Assuming that the vehicle technology containing the following epistatic relations between its three elements: (1) the functionality of the engine depends only on the design choice of the engine; (2) the functionality of the suspension depends on the design choice of the suspension and the engine, and; (3) the functionality of the brake depends on the design choice of the brake, the suspension allele, and the engine.

The architecture of epistatic relations between these three elements can be represented (Altenberg, 1997) as the following interaction matrix (see Figure 4-1):

	n=1	n=2	n=3
functionality n=1	$\boldsymbol{x_{11}}$	0	0
functionality n=2	x_{21}	$\boldsymbol{x_{22}}$	0
functionality n=3	x_{31}	x_{32}	$\boldsymbol{x_{33}}$

Figure 4- 1: Matrix representation of the architecture

In figure 4-1, the *x*-value stands for the existing interaction between the corresponding components, for example, the *x*-value on *i* row *j* column stands for the extent to which the function of element *i* is influenced by a change of element *j*, the *x*-values along the rows *i* in the matrix indicate the vector of elements that affect the functioning of element *i*. The *x*-values along the columns *j* indicate the vector of elements the functioning of which is affected by the choice of allele of an element *j*.

It should also be noted that by definition, epistatic relations are always present on the diagonal as the functioning of a component depends on its own design. In the above matrix, these epistatic relations are denoted by bold ***x***-values.

In a complex system of technology, when interdependencies exist between elements, the change of the design for one element may increase its own functionality, but it may at the same time decrease the functionality of other elements that it epistatically affects. The higher the interdependencies between elements, the more likely an improvement in one element has negative by-effects on the workings of other elements, the more trade-offs are present in a system, and the more difficult the search for a good design will be (Frenken, 2001c; Rosenberg, 1969).

To compare the complexities of different systems, one needs to characterise the complexities of their architectures. The major difficulty in characterising the complexity of an architecture is that even for relatively small systems, there is an exponentially larger number of possible architectures[13][14], and it is impractical to analyse and compare the properties of all possible architectures of complex systems. For this reason, Kauffman (1993) restricted his analysis to those architectures in which each element is epistatically affected by the same number of other elements. The number is characterized by the parameter *K,* which captures the complexity of the structure of the system.

The NK-systems are then defined as systems with *N* elements in which each element is affected by *K* other elements. For systems with minimum complexity without any epistatic relation, the K-value is lowest ($K=0$). For systems with maximum complexity where each element is epistatically related to all other elements, the K-value is highest ($K=N-1$).

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[13] More generally, in a system with *n* elements, the number of possible architectures is $2^{n(n-1)}$, as for all cells except those on the diagonal, an epistatic relation can be either present or absent.

[14] For example, in a simple system with two elements, there are four possible relations (1) absence of any epistatic relation; (2) one epistatic relation from the first to the second element; (3) one epistatic relation from the second to the first element, and; (4) two mutual epistatic relations.

A fitness function π: $A_1 \times A_2 \times \ldots A_N \rightarrow [0, 1]$ is then defined which assigns a (normalized) real number to each possible string (design/decision vector) [15] ***s*** ($=s_1 s_2 ... s_N$) as a measure of its relative performance. The fitness of the string ***s*** is usually defined as the mean value of the fitness values (π_n) of each of its allele (s_n), which are in turn randomly drawn from a uniform distribution over [0, 1].

More formally, the fitness function is given by:

$$\pi(s) = \frac{1}{N} \cdot \sum_{n=1}^{N} \pi_n \, (s_n) \tag{4.3.3}$$

As mentioned above, in the NK model, the parameter *K* measures the degree of interdependence between the N elements. This means, the contribution of each allele s_n (n=1, 2,…, *N*) of a string ***s*** to the overall fitness is dependent both upon its own state and the states of *K* other elements. For example, when there is an epistatic relation from element *j* to another element *i,* the change in the state of element *j* will cause a change in the payoff contribution of element *i* (the fitness value of element *i* is simply redrawn from the underlying distribution). As the focal design/decision choice regarding element *i* is epistatically affected by the choices regarding *K* other elements, its payoff will be redrawn whenever any of the K coupled decisions change.

Given that the fitness function is also influenced by the parameter *K*, function (4.3.3) can be written as (Altenberg, 1997):

$$\pi(s\,; N, K) = \frac{1}{N} \cdot \sum_{n=1}^{N} \pi_n \, (s_n ; s_{n_1}, s_{n_2}, \cdots, s_{n_K}) \tag{4.3.4}$$

where $\{n_1, n_2, \cdots, n_K\} \subset \{1, \cdots, n\text{-}1, n\text{+}1, \cdots, N\}$, meaning that for any *n* (n=1, 2,…, N), we obtain a *K* dimension vector of indexes (n_1, n_2, …, n_K) mapping from *N* to N^K, none of which can be equal to *n*, the notation n_k means that the index is the *k*th element of the vector.

4.3.4 Some Properties of the NK Systems

Let's look at the following two examples adapted form Frenken (2001c), in both cases, the system is characterized by N=3, $A_i \in \{0, 1\}$. In the first example, we

[15] As the number of possible states for each element is often reduced to two, a string $s \in S$ *is* a vector of binary digits of length *N*.

consider a system with minimum complexity (K=0), all elements function independently from each other (see Figure 4-2). Figure 4-3 presents a result of simulated fitness values. The distribution of fitness values for different designs s in the design space is called a "fitness landscape". The design space of this 3 elements system contains 2^3 possible strings, which can be represented as coordinates in the three dimensions of a cube. The fitness landscape of the system is presented in Figure 4-4.

	n=1	n=2	n=3
functionality n=1	1	0	0
functionality n=2	0	1	0
functionality n=3	0	0	1

Figure 4- 2: Architecture of N=3-system with K=0[16]

	π_1	π_2	π_3	π
000:	0.2	0.6	0.8	0.53
001:	0.2	0.6	0.5	0.43
010:	0.2	0.9	0.8	0.63
011:	0.2	0.9	0.5	0.53
100:	0.7	0.6	0.8	0.70
101:	0.7	0.6	0.5	0.60
110:	0.7	0.9	0.8	0.80
111:	0.7	0.9	0.5	0.70

Figure 4- 3: Table of Simulated Fitness Values (N=3, K=0)

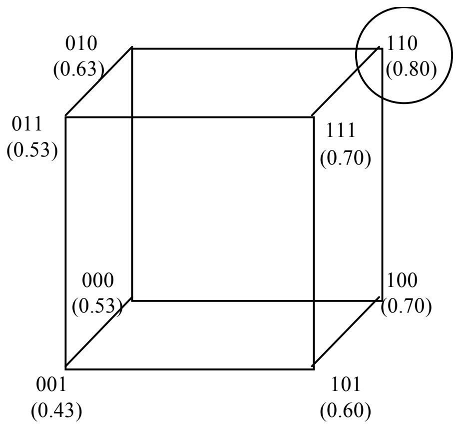

Figure 4- 4: Fitness Landscape of a N=3-system with K=0

[16] For simplicity, we denote the N rank interaction matrix M as $[m_{ij}]$, $m_{ij} \in \{0,1\}$, where m_{ij}=1 indicates that element j affects the functioning of element i.

Source: Frenken (2001c)

In the second example, we consider a system with maximum complexity (*K=N-1=2*), the functioning of an element depends on the design choice of all other elements (see Figure 4-5). As mentioned above, whenever there is an epistatic relation from element *j* to another element *i,* a change in the state of element *j*, will cause the redrawing of the fitness value of element *i*. In the case of maximum complexity, to simulate the fitness landscape of the system, the fitness value of any allele of any element is randomly drawn. An example of the simulated result of fitness values and the fitness landscape of an N=3-system with *K*=2 are given in Figure 4-6 and Figure 4-7.

	n=1	n=2	n=3
functionality n=1	1	1	1
functionality n=2	1	1	1
functionality n=3	1	1	1

Figure 4- 5: Architecture of N=3-system with K=2

	π_1	π_2	π_3	π
000:	0.5	0.1	0.7	0.43
001:	0.2	0.2	0.8	0.40
010:	0.7	0.8	0.6	0.70
011:	0.6	0.5	0.3	0.47
100:	0.9	0.5	0.8	0.73
101:	0.2	0.3	0.4	0.30
110:	0.5	0.9	0.4	0.60
111:	0.4	0.8	0.1	0.43

Figure 4- 6: Table of Simulated Fitness Values (N=3, K=2)

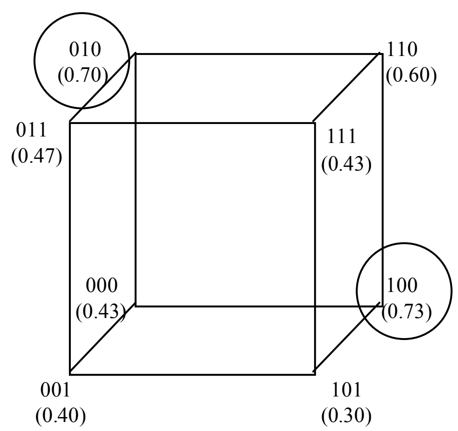

Figure 4- 7: Fitness Landscape of a N=3-system with K=2

Source: Frenken (2001c)

Before comparing the properties of the two systems, let us introduce some relevant concepts. In the NK model, the ***immediate neighbourhood*** (local) for a string (design vector) is defined as all the strings (vectors) that differ at most by one bit (allele) from the focal string. For an N-element system, each string has N neighbours. A ***local peak*** in the fitness landscape is a point such that all its N neighbouring strings have a lower fitness value. In economic applications of NK model, the ***local trial-and-error search*** is the most basic search strategy which is considered as being analogous to natural selection in its original setting of biological evolution (H. A. Simon, 1969). Specifically, a ***local trial-and-error search*** is one based on randomly changing the allele of one element in a string. A trial thus implies that one moves along one dimension in the cube from one string to a neighbouring string, and it proceeds by evaluating the fitness values of the new and the old string. If the trial turns out to increase the fitness value, the agent moves on searching from the new string, while a lower fitness value induces the agent to return to the previous string, and continue the next move from there. In a fitness landscape, local trial-and-error means that search will continue as long as there exists at least one neighbouring string that has a higher fitness value, and it will halt when a local peak is found (i.e., there is no room for improving the fitness value by changing the allele in one element). Search can thus be considered as an "adaptive walk" over a fitness landscape towards a "peak", and it will halt only when a local peak is reached. Following the metaphor of the fitness landscape, search in complex technological systems can be considered a process of "hill-climbing" (Kauffman, 1993). Like a hiker climbing in a dense fog, a searcher can only see the portion of the landscape that immediately surrounds their current position. They do not know whether the peak they found is the only (global) peak or whether an even higher mountain lies just past an adjacent valley (Sorenson, 2002).

In the N=3 K=0 system, the fitness landscape is relatively smooth as the change of any single bit causes only its own contribution to be redrawn, and the fitness values of two adjacent strings change gradually. By contrast, a higher K value (as in the case of K=2) implies a more rugged landscape. This is the case because a higher degree of interdependencies (a higher K value) between elements suggests that a change of single bit—which triggers the redrawing of the payoffs of K other elements in addition to changing its own performance contribution—may cause a dramatic change in the overall fitness value. The ruggedness of fitness landscape can also be confirmed by the numbers of *local peak* in the fitness landscape. In the K=0 system (without any epistatic relation), the landscape contains only one local peak, whereas the landscape of systems with epistatic relations can have multiple local peaks. More generally, the number of local optimum increases with K and N (Altenberg, 1997; Kauffman, 1993). In a landscape containing several local peaks, the so-called ***local optimum*** and ***global optimum*** can be distinguished. Local optima have sub-optimal fitness values compared to that of the global optimum. In figure 4-7, string 100 is a global optimum since its fitness value is the highest of all strings, while string 010 is a local optimum since its fitness is higher than the fitness of its neighbouring strings, but lower than the fitness of the global optimum.

As the elements of a K=0 system work independently, Optimisation is easy since a design change in one element does not affect the functioning of other elements. Put differently, systems without complexity do not have trade-offs between the functioning of elements. Therefore, each element can be optimised independently through local trial-and-error. A series of local trial-and-error searches will always lead the designer to the only optimal system design (e.g., 110 in figure 4-4). In this sense, local trial-and-error in systems with no complexity ($K=0$) is path-independent as the global optimum is the only optimum, and any search sequence finally ends up at this optimum.

By contrast, local trial-and-error search in complex systems ($K \neq 0$) will not always lead to the optimal solution. As mentioned above, the number of local optimum increases with K. That means, for systems with higher complexity K, it becomes increasingly more likely that local trial-and-error leads to a local optimum rather than the global optimum. For example, in figure 4-7, the search could get stranded at 010, even though it is not the global optimum (100 corresponds to a globally highest fitness value). Once a local trial-and-error search ends up with a local optimum, the search is "locked in". In a complex system with multiple local optima, with which specific local optimum a local trial-and-error search would end up depends on the starting point in the landscape and the particular sequence of the search. In this sense, the result of a search is path-dependent on its initial starting point, and the sequence of search that follows.

4.3.5 Insights from Applications of MK Model in Strategy and Organization Literature.

Four years after the publication of Kauffman's seminal book, the model was introduced to the field of strategy research by Daniel Levinthal (1997) who demonstrated in a NK simulation model that persistent inter-organizational heterogeneity can be explained in terms of the interdependencies among the firm's decision choices.

Researchers in this field soon found that the *NK* modelling technique can be easily translated into organizational settings to generate insights (Sorenson, 2002). Its formal structure allows one to clearly define complexity and to precisely delineate adaptation mechanisms, which helps not only to clarify the association between particular strategies (adaptive principles) and performance (fitness) in more or less complex environments, but also to observe intuitively the underlying process (Ganco & Hoetker, 2009).

Levinthal's (1997) highly influential paper spurred the applications of the *NK* model to economics- and strategy-related issues. Apart from a few contributions that focus on the technical properties of the *NK*-model (e.g., Frenken et al., 1999; Rivkin & Siggelkow, 2007), these applications can be divided into two broad categories which address "different systems of reference" (Frenken, 2001b). In the first category, researchers aim at translating the properties of the NK-model to issues of firm strategy (Ethiraj & Levinthal, 2004a; Gavetti & Levinthal, 2000; Levinthal, 1997; Rivkin, 2000, 2001; Rivkin & Siggelkow, 2003; Siggelkow & Rivkin, 2005). Following earlier approaches in organization theory (March & Simon, 1958; Thompson, 1967), this branch of literature concentrates on the relationship between decision interdependencies, environmental uncertainty/complexity and organization strategy.

The second category of applications explore technological problem-solving (or a production technology) as an evolving NK-system (Auerswald, Kauffman, Lobo, & Shell, 2000; Brusoni, 2005; Dosi et al., 2011; Dosi & Grazzi, 2006; Ethiraj & Levinthal, 2004b; Fleming, 2001; Fleming & Sorenson, 2004; Frenken, 2006a, 2006c; Kauffman et al., 2000; Marengo & Dosi, 2005; Luigi Marengo et al., 2000). Although concerned with different systems (strategy and technology, respectively), the fundamental insights of these two categories of application seem to converge.

Below, we summarize the major insights of these applications.

One of the key tenets of earlier organization theory is that the underlying pattern of task interdependence defines appropriate organization (Lawrence & Lorsch, 1967a; H. A. Simon, 1962; Thompson, 1967). The first category of applications of the NK model can be seen as a revival and extension of this earlier work. In this literature, the above logic is applied to explore the nature of search and adaption in a particular environment, and it attempts to identify the pattern of association between environmental complexity, firm strategy, and performance (Leiblein & Macher, 2009). Specifically, in these studies, the NK model is used as a metaphoric device to examine whether and how an organization with particular attributes (or following a specific strategy in making its choices) manages to navigate itself to a more attractive position within a fitness landscape. Typically, these approaches describe *N* and *K*, respectively, as the ***number*** and ***interdependence*** of organizational choices or "strategic" attributes of an organization, and the fitness landscape is used to indicate its performance or survival propensity.

In the second category of applications, *N* represents the number of knowledge sets and *K* the interactions among them, and technological problem solving is viewed as a process of searching over the solution landscape for high value solutions. Specifically, each solution to a problem consists of a string of binary design choices which yields a distinct solution value, and each binary design choice is informed by a particular knowledge. For any given problem, the set of all possible combinations of relevant existing knowledge is represented by the solution landscape, the topography of which defines the value of any given solution (Nickerson & Zenger, 2004).

As in the original *NK* model, in these *NK* modelling applications, agents/organizations can change their fitness landscape positions/status either through selection or through adaptation (Leiblein & Macher, 2009). Selection occurs as organizations with "superior" bundles of attributes have more freedom to move across the fitness landscape, while those with ''inferior'' bundles might eventually be forced to exit. Adaptations occur when agents/organizations, through search efforts, improve their performance (fitness level) by modifying their existing attribute/choice profiles.

While differences exist across applications, the overall implications of the initial applications of the *NK* model tend to suggest that: (1) while agents/organizations attempt to navigate themselves to a more attractive position (i.e., more profitable, greater chance of survival, higher value of solution, etc.) in the fitness landscape, their ability to judge the attractiveness of alternative attribute or choice profiles is both imperfect and diminishing with distance (Leiblein & Macher, 2009). On the more rugged landscapes, a series of incremental changes of choice is unlikely to lead to the discovery of highly valuable fitness points. Lacking knowledge of the entire landscape, a agent/organization is often stuck in "local peaks" such that marginal change along any one attribute/choice dimension diminishes performance (Levinthal, 1997; Nickerson & Zenger, 2004); and (2) performance variation can be explained in terms of inter-organizational differences in initial position, the magnitude and type of search efforts, and expected adaptation costs.

One might find that the above implications are basically the same as those derived from biological models, but now reiterated in the realm of economics and strategy. Many researchers (Bresson, 1987; March, 1988; Nelson, 1995) have noted that although biological analogies have contributed powerful heuristics to economic theorising of organizational/technological change, important differences exist between the evolution of organisms and the evolution of economic/technological systems. In particular[17], in the original *NK* model which forms the starting point for many applications in the organization and strategy literatures, it is assumed that interactions among elements are randomly determined[18], and the "movement" on the fitness landscape is realized through the random mutation in a single gene (i.e., via local trial-and-error search). Although these assumptions might be appropriate for biological systems, their validities for organizational/technological systems are dubious since in organizational/technological systems, human agents employ more sophisticated methods of search (Frenken, 2001a; Sorenson, 2002).

Recent applications in economic and strategy literatures tried to address this problem. With the help of the formal structure of the *NK* model[19], these applications try to demonstrate the linkage between particular adaptive principles (search methods) and their outcomes in more or less complex environments. Overall, these studies have contributed valuable new insights regarding the interdependencies between information availability, coordination challenges, and relative efficiencies of different search methods when exploring landscapes of different complexities. In particular, different search methods, which range from local trial-and-error to distal, heuristic search, have been shown to produce different expected search outcomes (fitness levels) on landscapes of different degrees of ruggedness (i.e., the complexity of the environment/problem) (Leiblein & Macher, 2009). To be more exact, it has been shown that complexity increases the likelihood of conflicting constraints across

[17] Another difference between biological and economic/technological evolution concerns the role of imitation. In the economic/technological context, imitation has been regarded as an alternative strategy to innovation (Alchian 1950), and it has been argued that under some circumstances, imitation can be more effective than innovation as the imitating firm bears less R&D expenditures (Lieberman & Montgomery, 1998). However, the simulation results of the NK models tend to suggest that imitation is hardly effective even when the targeted technology is moderately complex (Rivkin, 2000, 2001).

[18] If the interactions among elements are not random, the interactions exhibit some pattern. In the existing literature, hierarchy and decomposability are two of the interaction patterns that received most attention; however, there are other possible patterns, for example, small-world connection. See Rivkin and Siggelkow (2007) for a general discussion.

[19] In the NK model, both the degree of complexity and the type of adaption mechanism can be clearly defined.

choices, adds to the difficulty of finding the global optima, thus degrading the efficacy of local trial-and-error search (Rivkin, 2000). By contrast, the relative efficacy of heuristic search[20] is greater in more complex environments but it is less effective in less complex environments (Gavetti, 2005; Gavetti & Levinthal, 2000; Sommer & Loch, 2004; Winter et al., 2007).

Apart from establishing the associations between the expected efficiency of various search mechanisms and the complexity of environments/problems, recent applications of NK models have linked particular attributes of organizational form to specific search methods, suggesting that different governance mechanisms might have different efficiencies in implementing different search methods, which in turn, exhibit different search performances on landscapes of different complexities. In particular, some organizational attributes, such as the use of hierarchical and/or divisionalized/departmentalized structure, have been shown to have substantial ramifications on search efficiency.

Rivkin and Siggelkow's study (2003) is one of the first few [21] in this line. They argue that organizational design affects firms' performance by altering their search behaviour on the landscapes they face. They identify broad search and stability as the critical trade-off in designing organization structure—while some specific elements of organizational design drive a firm toward broad search, others encourage stability. In particular, their simulation results indicate that "an active vertical hierarchy tends to be more valuable when interactions among decisions are pervasive"[22], but "this benefit arises only if the information flow in the hierarchy is rich enough" (Rivkin &

[20] For example, Gavetti and Levinthal (2000) introduce heuristic search in the NK model where managers use cognitive maps to navigate their searches. These cognitive maps are lower-dimension representations of higher-dimension landscapes. They lack details but provide a rough reference of the underlying topography. Not surprisingly, when these maps correctly reflect the underlying landscapes, managers achieve better search outcomes. Most interestingly, even if these maps do not represent the landscape well, managers are still able to improve their search outcomes. This seems to suggest (Sorenson, 2002), in the absence of any cognitive representation of the landscape, a manger tends to stop searching once he finds a local peak. By contrast, if a manager is following a cognitive map—right or wrong as it may be—he can tolerate a longer period of poor performance and keep on searching until a reasonably good point on the landscape is found. In short, the manager achieves better search outcomes simply because of the belief that a better alternative exists somewhere around. Winter, Gattnai, and Dosch (2007) come to a similar finding, they conclude that moderate obsession is distinctly advantageous in searching a rugged landscape. An interesting implication of this finding is that management gurus, regardless of the veracity of their claims, may serve a useful purpose by giving managers the confidence to implement painful changes (Sorenson, 2002).

[21] Marengo et al.'s (2000) study is even earlier but it focuses more narrowly on the relation between decomposability of the problem and the structure of organization.

[22] To Rivkin and Siggelkow (2003), a vertical hierarchy is the most common mechanism employed to coordinate the decisions of separate decision makers in which a CEO sits above a set of subordinated departments. In other words, to the authors, a hierarchy is characterised by authority/subordination relation. See also footnote 27.

Siggelkow, 2003: p. 292). On the other hand, "if decisions can be decomposed"—i.e., be parsed out to departments—"in such a way that few cross-departmental interactions remain, the value of an active vertical hierarchy declines" (Rivkin & Siggelkow, 2003: p. 294).

Following this line of inquiry, many other subsequent studies report similar results in various settings (Brusoni et al., 2007; Ethiraj & Levinthal, 2004a; Marengo & Dosi, 2005; Mihm, Loch, Wilkinson, & Huberman, 2010).

In a NK simulation model, Ethiraj and Levinthal (2004a) examine Simon's (1962) insight that the dual properties of hierarchy and near-decomposability[23] will enhance the evolvability (i.e., adaptation efficiency) of complex systems. *Inter alias*, their model tries to address the following problems: (1) Given that complex systems are of different architectures (in terms of hierarchchical strucure and decomposibility), how can the appropriate orgnizational structure be designed[24] to facitates the discovery of the true structure of the underlying problem (system)? In other words, what kind of organizational structure is better able to realize second-order adaptation[25]? (2) Do efforts to realize second-order adaptation (design efforts) complicate or complement the effectiveness of first-order adaptation efforts[26], and to what extent is local trial-and-error search effective?

In addressing these questions, they show that the relative effectiveness of these adaptation efforts (searches) vary systematically with regard to the architectures of complexity.

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[23] According to Simon, a hierarchic system, or hierarchy, is "a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem" (1962: p. 468), while nearly decomposable systems are systems "in which the interactions among the subsystems are weak, but not negligible" (1962: p. 474). The two authors (Ethiraj & Levinthal, 2004a: p. 404) interpret Simon's definitions of hierarchy and near-decomposability as indicating the fact that "*some decisions or structures provide constraints on lower-level decisions or structures*", and that "*patterns of interactions among elements of a system are not diffuse but will tend to be tightly clustered into nearly isolated subsets of interactions*", respectively.

[24] In this model, managers, being the system designers, are assumed to have control over the number of departments and the assignment of functions to them. In particular, they can either split an existing department into two or more new departments, or combine two or more into one, or reallocate functions among them in accordance with the underlying mapping of the decision variables.

[25] In the management literature, first-order adaptation is defined as incremental, local adaptation within a given structure that involves the working out of specific choices within that given structure. By contrast, second-order adaptation represents the change in the underlying structure itself.
In the context of the NK model, the challenge of the second-order adaptation entails discovering the pattern of interactions among the N decision variables, and clustering those decision variables that seem to have strong interactions with each other.

[26] In the context of the NK model, the first-order adaptation corresponds to the usual one-bit mutation (local trial-and-error search) implemented simultaneously in each department.

Specifically, they set up four alternative states of the world (what they call "***generative structures***") that vary in terms of the underlying architecture of complexity along the two dimensions of hierarchy[27] and decomposability: (1) hierarchical and nearly-decomposibe; (2) non-hierarchical and nearly-decomposable; (3) hierarchical and non-decomposble; and (4) non-hierarchical and non-decomposble.

In a similar fashion, organization structures are characterized into four categories. In a loosely (tightly) coupled organization, there are few (many) interdependencies between departments; along the second dimension, the organization is said to be "hierarchical"[28] (non-hierarchical) if the structure of interdependencies between departments is unidirectional[29] (reciprocal).

Their simulation results tend to reaffirm and formalize the intuition behind Simon's insights. To be more exact, a "hierarchical" organizational structure[30] is shown to be "a necessary and sufficient condition for the success of design efforts"[31] (Ethiraj & Levinthal, 2004a: p. 432). In other words, compared with a non-hierarchical structure (reciprocal rather than unidirectional interaction between departments), hierarchy is more efficient in discovering the true underlying generative structure and realizing second-order adaption[32]. By contrast, "near-decomposability is a necessary and

[27] It should be noted that in the literature, there are at least two meanings to the term hierarchy (Zhou, 2012)—the hierarchical structure of a ***task system*** (complex system) and the hierarchical structure of an ***organization***. The hierarchical structure of the task (complex) system captures the ***directionality of interdependence among tasks or subsystems***. While the hierarchical structure of the organization, by contrast, represents the vertical structure that coordinates between organization units (Holmstrom and Tirole, 1989)—a relation of ***subordination*** among subsystems to which Simon referred as "formal hierarchy" (Simon, 1962: p. 468). It should be emphasized in particular that in this paper, the two authors use the terms ***only in its first meaning*** (as the authors state explicitly that "the meaning of hierarchy in our models is simply the unidirectional flow of decision constraints" and such a unidirectional flow is a result of "the ordering of decision constraints between sets of activities at a point in time") (Ethiraj & Levinthal 2004a, p. 415), even though the term has been used both to describe a complex system, and to represent a type of organizational structure. In the author's view, such a practice leads to some confusion.

[28] Here, the term "hierarchical" is used to indicate the ordering of decision constraints rather than an authority/subordination relation. It should be noted that such usage is different from its common usage in most organizational contexts.

[29] That is, the decisions of the first department influence the decisions of the second department, but not the other way around.

[30] See footnote 28.

[31] It is shown that in the case of adopting a hierarchical organizational structure, the managers (organization designer) are always able to "successfully converge on the underlying generative structure" (Ethiraj & Levinthal 2004a, p. 422).

[32] The authors' conception of hierarchy, especially about its relative efficiency in realizing the "second-order adaptation" by discovering the true "generative structure", is very much similar to the argument that hierarchies enjoy advantages in implementing "heuristic search". Specifically, the authors argue that the function of hierarchy is not only to resolve conflicts between sub-systems; more importantly, it is a (nested hierarchy) structure (Baum & Singh, 1994) embodying "a precedence

sufficient condition for the success of incremental performance improvement efforts" (first-order adaptation) (Ethiraj & Levinthal, 2004a: p. 432)—that is, local trial-and-error search is effective only when the system is nearly decomposable and the true decomposability structure has been correctly identified (i.e., the relevant decision variables have been correctly departmentalized). Moreover, they find that first-order and second-order adaptation are generally complementary[33], though the degree of complementarity depends on the nature of the underlying interaction structure. Specifically, whereas the complementarity is non-zero and highly positive when the underlying generative structure is nearly-decomposable, such complementarity is significantly lower when the underlying generative structure is non-hierarchical and non-decomposable, as second-order adaptation (design effort) by itself is completely ineffective for non-hierarchical and non-decomposable systems. When the underlying architecture of complexity (i.e., the generative structure) exhibits some combination of hierarchy and decomposability, first-order and second-order adaptation are both crucial, an efficient organization design thus requires a corresponding combination of hierarchical structure and departmentalization.

Marengo, Dosi and their collaborators' studies (Marengo & Dosi, 2005; Luigi Marengo et al., 2000), by contrast, focus on the relationship between decomposability of problem and the organization of problem-solving[34]. More specifically, the question they are concerned with is basically a question of organizational choice—can optimal technological design emerge from decentralized local search?

Their NK simulation results indicate that along different levels of task decomposition, there is a subtle trade-off between the degree of sub-optimality of the achievable outcome and adaptation speed. To be more exact, a finer decomposition makes search faster, but the exploration of smaller portions of the landscape reduces the likelihood of discovering an (globally) optimal solution. This implies: the advantages

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ordering of tasks or activities" (Ethiraj & Levinthal, 2004a: p. 409). In the context of organization design, the line of hierarchy denotes the flow of information, or the sequence/priority of decision-making, which facilitates learning by allowing systematic and orderly (directional) search and exploration.

[33] According to the two authors, the underlying reason for such complementarity is that second-order adaptation, even if unsuccessful, is reasonably effective in identifying the neighbouring high performing organizational forms. From the standpoint of first-order adaptation, specifying a design that is in the vicinity of the correct design is still significantly better than a random trial.

[34] Brusoni et al.'s research (2007) is roughly in the same line. As noted by the authors, "modularity is in fact a decomposition heuristic, through which a complex problem is decomposed into independent or quasi-independent sub-problems" (2007: p. 121). This short statement indicates clearly the link between decomposability, modularity and search heuristics.

(faster adaptation) of decentralized modes of organization[35] associated with a finer decomposition of the task usually bear a cost in terms of sub-optimality (impossibility to reach global optima). The implication casts doubt on the general validity of the "optimality through selection" argument, or more generally, of any "optimistic" view of market selection processes in which the market mechanism is argued to be capable of realizing evolutionary optimization (Alchian, 1950; Friedman, 1966).

If the underlying problem is near-decomposability—that is, if the problem can be divided into sub-problems which contain the most relevant interdependencies, while less relevant ones still persist across sub-problems—optimizing each sub-problem independently will not generally lead to the global optimum, but to a reasonably "good" solution. In this case, the adoption of decentralized organizational modes could at least be partially justified on practical grounds[36].

Overall, the insights of the stream of literature that links organization forms, search mechanisms and problem complexities seem to suggest: the desired structure of the organization should try to mirror the "true" structure of the underlying problem or decisions (in terms of the nature of interdependencies between its elements, hierarchical and/or decomposable), so as to stimulate the development of desired interdependencies and to facilitate the adaptation and problem-solving.

Summing up, the recent applications of the *NK* model in the economic and strategy literatures have deepened our understanding of the functioning of different search and adaptation mechanisms in more and less complex landscapes. In particular, it has brought precision to the concept of complexity and provided important insights regarding the efficacy of local and heuristic search in landscapes of different degrees of complexity (Leiblein & Macher, 2009). Moreover, in these applications, certain elements of organizational form have been linked to some specific search mechanisms, but it is not entirely clear whether and how different organizational

[35] These decentralized modes of organization can either be coordinated via market-like mechanisms, or via simple organizations structured as sets of independent tasks.

[36] The authors note that on the empirical side, the above trade-off provides a plausible mechanism that explains the observed changing pattern of the integration along technology and industry life cycles. Specifically, vast empirical evidence suggests that major new technologies often develop within highly integrated organizations because of the need to coordinate the strong interdependencies that characterize difficult problems. Market-like decentralized mechanisms do not provide advantages in this early phase, because they do not allow for the coordination of interdependent elements. As search proceeds, the dominant structure (a set of standards in the techno-organizational design problem) emerges. The degree of decentralization can be greatly increased in order to allow for speedy search by parallelism. Nevertheless, the trade-off between decentralization and optimality is still hard to avoid.

forms differ in their competencies to implement different types of search. Relatedly, most of the efforts in these applications have been devoted to the understanding of the dynamics of ***intra-organizational*** search and problem-solving, especially those associated with the ***coordination*** issues. By contrast, incentive issues (Dosi et al., 2011), and the ***inter-organizational*** governance implications[37] associated with problem-solving and adaptation/search efforts (Leiblein & Macher, 2009), are seriously under-explored. Once inter-organizational issues are considered, however, problems of ***incentive compatibility***, ***opportunism*** and ***exchange hazards*** become salient. In addition to articulating the mechanisms through which different organizational forms facilitate the ***coordination*** of particular types of search, it is also necessary to understand whether and how these different organizational (governance) mechanisms address ***incentive*** issues (e.g., potential exchange hazards) associated with particular types of search. In short, the researchers have yet to identify the few critical attributes that dimensionalize different organizational forms in terms of their coordinative and incentive capacities to implement different search and problem-solving methods. Finally, as with all simulations, the assumptions and setups in any specific *NK* model may or may not capture the most critical features of the underlying systems. As a consequence, without further empirical corroboration, we never know whether and to what extent the insights generated by the NK model are valid, no matter how plausible they might look. In this sense, empirical corroboration is not only a complement, but also a must, an absolutely needed second step for a successful application of the NK model.

4.4 The Problem-Solving Perspective

In this section, we review the literature on the problem solving perspective.

4.4.1 Overview

The value of a problem is ultimately determined by the value of the discovered solution. Therefore, once the problem has been identified, the next critical task is to organize an effective solution search for the chosen problem.

Although adopting a different unit of analysis from TCE, the problem solving perspective applies similarly the logic of "discriminating alignment" (Williamson, 1991) in evaluating the relative costs and competencies of alternative governance mechanisms in solving problems with different attributes. Specifically, based on

[37] These inter-organizational mechanisms include: joint venture, equity-alliance, R&D co-development contract, etc.

Simon's work on problem solving (1962, 1973) and certain contributions to the knowledge-based view which explore how different organization modes affect the transmission of information and the coordination of knowledge sharing, the problem-solving perspective identifies a few critical dimensions (problem attributes and knowledge characteristics) along which the coordination and incentive challenges to problem-solving activities differ systematically; different search methods and different problem types are then matched in a way that better meets these challenges and realizes superior search performance. Moreover, it is also identified that as far as the costs and competencies for implementing solution searches (via different search methods) for different types of problem are concerned, a few generic organizational modes differ with respect to the dimensions of incentive intensity, communication channels, and dispute resolution regime (Heiman & Nickerson, 2002, 2004; Leiblein et al., 2009; Nickerson & Zenger, 2004). Finally, the problem-solving perspective works out the match between these problem/knowledge attributes and the few generic organizational modes in an economizing manner that enables efficient solution search and maximizes expected values of problem solving (Heiman & Nickerson, 2002; Leiblein & Macher, 2009; Macher, 2006; Nickerson & Zenger, 2004).

Below, the discussion proceeds in the following order. In 4.4.2, we discuss the dimensioning of problems; in 4.4.3, we introduce different search methods; in 4.4.4, we identify incentive and coordination challenges to problem solving; in 4.4.5, we discuss the discriminating alignment between problem types (knowledge characterises) and organizational modes; in 4.4.6, we present some extensions of the problem solving perceptive to the case of inter-firm collaboration.

4.4.2 Dimensionalize Problems

Based on Simon's work on problem solving (1962, 1973) and Kogut and Zander's contributions to the knowledge-based view of the firm (1988; 1992, 1993, 1995), a few problem attributes (such as problem complexity, decomposability, and problem structure) and knowledge characteristics (such as knowledge tacitness and social distribution) have been identified as being critical along which the coordination and incentive challenges to problem-solving activities differ systematically.

In this perspective, the "problem" is taken as the basic unit of analysis, and the profitable discovery of a high-value solution to a problem (i.e., formation of new knowledge) is the central rationale for choosing the organizational form. Following previous work, it is assumed that new knowledge is generated by combining existing knowledge, and a solution to a complex problem represents a unique combination (synthesis) of existing knowledge. For any given problem, the set of all possible combinations of relevant existing knowledge (i.e., solutions) is represented as a solution landscape the topography of which defines the value of each solution, and the solving of the problem is viewed as a process of searching over the solution landscape for high value solutions (Nickerson & Zenger, 2004).

A. Complexity and Decomposability

Based on Simon's work on complex systems as well as insights derived from the NK modelling, these two dimensions were first introduced to the PSP literature by Nickerson and Zenger (2004).

According to Simon (1962), complexity obtains when a large number of parts that make up a system "interact in a non-simple way" (1962: 468). As a system, complexity frequently takes the form of a "hierarchy"—that is, a system is often composed of interrelated subsystems which, in turn, are hierarchical in nature until some elementary subsystem is reached at the lowest level. In hierarchic systems, one can distinguish between the interactions among subsystems and the interactions within subsystems. This forms the basis for the distinction between decomposable, non-decomposable and nearly decomposable systems. In a decomposable system, the interactions among the subsystems are *negligible*; by contrast, in a non-decomposable system, the interactions among the subsystems are *essential*; while in a nearly decomposable system, the interactions among the subsystems are *weak*, *but not negligible* (1962: 129).

With reference to the *NK* system, the complexity of a problem is defined in terms of the number of relevant knowledge sets for a given problem (*N*), and the magnitude or degree of interdependence (*K*) among these knowledge sets (Nickerson & Zenger, 2004). In other words, problem complexity depends on the number of relevant variables (design choices) on the one hand, and the degree of interactions among these variables on the other hand. Simple problems involve a small number of relevant knowledge sets which interact in more predictable ways. By contrast, complex problems entail a larger number of relevant knowledge sets among which there are pervasive interactions and extensive connectivity, some of which does not allow direct observation (high in-transparency) (Funke, 1991). Intuitively, as the number of *N* and *K* increases, the likelihood of conflicting constraints across choices tends to increase (Kauffman, 1993), the solving of complex problems thus requires the balancing of multiple variables, which adds to the difficulty of finding the global optima, and places higher cognitive burdens on problem solvers (Frenken, 2001b; Jonassen, 2004).

The complexities of problems also differ in terms of decomposability (Ethiraj & Levinthal, 2004a, 2004b; Frenken et al., 1999; Luigi Marengo et al., 2000; Rivkin & Siggelkow, 2003; H. A. Simon, 1962, 2002). Based on the extent to which the relevant knowledge sets interact to produce a valuable solution (Nickerson & Zenger, 2004), problems can be categorized into three broad categories: decomposable, nearly decomposable, and non-decomposable problems. For (fully-) decomposable problems, the interdependencies among relevant knowledge set are negligible; as a result, such problems can be easily decomposed into sub-problems. Solving such problems requires little or no coordination and knowledge sharing; impediments to knowledge sharing are less relevant. Decomposability also implies that the solutions to each sub-problem are additive, which means that each sub-problem can be solved independently and the optimal solutions to each sub-problem can be readily aggregated to form a global optimum for the original problem.

On the other extreme of decomposability are non-decomposable problems. For such problems, there exist intensive and extensive interactions between relevant knowledge sets; consequently, they cannot be decomposed into sub-problems. To solve such problems, cognitive search is prescribed and the problem solvers need to develop cognitive maps (rough theories) to guide the search heuristics (Fleming & Sorenson, 2004; Gavetti & Levinthal, 2000; H. A. Simon, 1991). The development of such (shared) cognitive maps, in turn, requires knowledge sharing and exchange among multiple actors. As specialists from different fields are cognitively constrained in the speed with which they can learn, they may not even have the common grounds to communicate with each in the short run. That means, the matter of ***coordinating*** and aggregating specialists' knowledge, by itself, is a great challenge (Hsieh et al., 2007). Moreover, in the face of self-interestedness, ***incentive*** impediments such as ***knowledge appropriation hazards*** and strategic ***knowledge accumulation hazards*** tend to complicate the organization of solution discovery (Nickerson & Zenger, 2004).

Between the two extremes of decomposability, there are nearly-decomposable problems. For these problems, the level of interactions among relevant knowledge sets is moderate, sub-problems associated with distinctive knowledge sets can be identified but non-trivial interdependencies among the sub-problems still remain. Near-decomposability also implies that interactions among knowledge sets within sub-problems are greater than among sub-problems. The solving of nearly-decomposable problems requires some coordination and a certain amount of knowledge-sharing; accordingly, the aforementioned coordination and incentive challenges (knowledge formation hazards) also apply but on a reduced scale.

B. Definiteness of Problem structure

In the literature of systems theory, the definiteness of problem structure has long been regarded as a distinct dimension of problem complexity (H. A. Simon, 1973). In the context of defending artificial intelligence against the critique that certain problems are too ill-structured (ill-defined) and accordingly too complex to be computationally solvable, Simon submits that virtually all problems presented to problem solvers are initially ill structured problems. They become well structured problems as the problem solvers become increasingly more familiar with and more prepared for the problem. According to Simon, "it is not exaggerating much to say that there are no well structured problems, only ill-structured problems that have been formalized for problem solvers" (H. A. Simon, 1973: p. 186), and such a formalization process renders them computationally solvable.

In short, the essence of the distinction made between ill- and well-structured problem is that the degree of problem complexity also depends on the extent to which the problem solvers knows about (or are prepared for) the problem[38], well-structured problems are outcomes of problem-defining processes.

In accordance with the criteria set by Simon (1973), which are intended to apply in the context of artificial intelligence, problems are well structured when: (1) all initial elements relevant to the solution of the problem are known and can be described; (2) solutions to the problem can be practically evaluated by some definite criteria of effectiveness or efficiency; (3) the problem solving technique must reflect the laws that govern the external world; and (4) solving the problem requires only practicable amounts of computing and the relevant information needed to solve the problem can be gathered with practicable amounts of search (i.e., at a cost substantially below infinity).

In the problem-solving perspective literature, the dimension of ill-vs.-well structured problem is first introduced by Jeffrey Macher (2006), who attempted to extend the perspective by further dimensionalizing attributes of the problem.

[38] To put this somewhat differently, the degree of problem complexity also depends on the availability of problem-solving techniques.

Following Simon, Macher (2006) argues that problems can be characterized along a continuum that ranges from ill-structured to well structured. The degree of definiteness depends on the characteristics of the problem domain on the one hand, and the availability and understanding of problem-solving mechanisms on the other. Ill-structured problems have poorly-defined initial states (Jonassen, 2004) (*N* and *K* are equivocal) and unexpected and/or unknown knowledge-set interactions (Levinthal, 1997), accordingly, the problem-solving approaches to such problems are indefinite or ambiguous. By contrast, well-structured problems are those with well-defined initial states (the *N* and *K* parameters are unequivocal) and well-understood knowledge-set interactions, the problem-solving approaches to such problems are explicit and well-accepted.

In particular, the defining difference between ill-structured and well-structured problems is that due to the poor level of understanding of knowledge-set interdependencies, no consensus approach/procedure exists for solving ill-structured problems (Fernandes & Simon, 1999; H. A. Simon, 1973). Such differences also determine the extent to which these problem types are decomposable (Ethiraj & Levinthal, 2004a; Levinthal, 1997), a connection between problem structure and decomposability could thus be established (Macher, 2006). Ill-structured problems cannot be decomposed because the knowledge-set interactions are often unexpected or even unknown. More generally, a lack of understanding as to whether and how relevant knowledge sets interact with each other makes solution search difficult. By contrast, the knowledge-set interactions for well-structured problems are better understood, making solution search more transparent.

C. The Nature of Contextual Knowledge: Tacitness and Social Distribution Knowledge

In addition to problem complexity, certain knowledge characteristics (such as knowledge tacitness and social distribution) have also been linked to the impediments to problem-solving activities.

In the knowledge-based view literature, the governance implications of these two knowledge characteristics have been discussed extensively (Hippel, 1994; Langlois, 1992; Langlois & Foss, 1999; Langlois & Robertson, 1995; Marengo, 1995; Spender, 1998; Tsoukas, 1996), and in particular, by Kogut and Zander (Kogut, 1988a; Kogut & Zander, 1992, 1993, 1995, 1996; Zander & Kogut, 1995).

At the heart of these contributions, is the argument that productive knowledge is often tacit and socially distributed—that is, knowledge required to perform a productive activity is often hard to articulate and not possessed by any single mind; instead, it is distributed among a group of interacting individuals, emerging from the aggregation of their tacit knowledge elements. In addition, such knowledge is often contextually sensitive in the sense that it can only be mobilized in a specific (often firm-specific) context of carrying out a multi-person task. Given these characteristics of productive knowledge, when knowledge is to be transferred across firm interfaces, a firm may have difficulties understanding the knowledge and capabilities held by another firm; both firms separately and jointly may "know more than their contracts can tell" (Kogut and Zander 1992). In this setting, the costs of negotiating and making contracts with potential partners, of teaching and communicating with potential suppliers become very real factors that shape the firm boundary (Langlois, 1992), and such costs are rather independent of considerations of opportunism (Kogut, 1988a; Kogut & Zander, 1992, 1993). Accordingly, it is argued that firms internalize the utilization of tacit and socially distributed knowledge as internal replication economizes the costs associated with the transmission of such knowledge. In this view, what the firms "do better than markets is the sharing and transfer of the knowledge of individuals and groups within an organization" (Kogut & Zander 1992: p. 383), and the firms can do so because they can supply a set of "higher-order organizing principles" (Kogut & Zander 1992: p. 388)—such as "shared coding schemes", "a shared language", "shared identity", etc.—to coordinate groups and transfer knowledge in a way that markets cannot rival.

Heiman and Nickerson (2002, 2004) extend the view by associating these two knowledge characteristics with the impediments to problem solving, and applying it to the context of inter-firm collaborations.

Based on Kogut and Zander's works on the governance implications of tacit and socially distributed knowledge, Heiman and Nickerson (2002, 2004) argue that inter-firm collaboration can be understood as a collaborative problem solving process via the combination of participants' distinct knowledge sets that are often tacit and dispersed. Given the cognitive limitations and self-interestedness of agents, these two knowledge attributes can interact with problem complexity to engender knowledge transfer problems, which in turn pose significant challenges in the process of searching for a valuable solution. Various administrative apparatuses (e.g., the adoption of high-bandwidth communication channels and the development of common communication codes) and governance mechanisms (e.g., equity-based arrangement) are thus chosen/employed to support knowledge sharing/transfer, to mitigate the associated coordination and incentive costs, and to facilitate the problem solving process.

4.4.3 Solution Search over Landscape

A. Two Different Search Methods: Directional vs. Cognitive Search

In the literature of systems theory and the NK model, it has been shown that the likelihood, speed, and cost of arriving at a valuable solution depend both on luck and on the method of search (Simon 1962). On the solution landscape, the trial can be represented by the movements along two different strings of design choices. Apart from random trial, there are two fundamental approaches in searching for a valuable solution: local trial-and-error search (directional search) and heuristic search (or cognitive search).

A.1 Directional or Local Trial-and-error Search.

In economic applications of the NK model, ***local trial-and-error search*** is the most basic search strategy usually considered as analogous to natural selection in the original setting of biological evolution (H. A. Simon, 1969). Specifically, a ***local trial-and-error search*** is one guided solely by feedback or experience from prior trials. Each time, the trial is pursued by changing one design element in a string. Depending on the resulting change in solution value, the trial will either proceed along the same path of search, or—in the wake of declining solution value—the trial would return to the previous string, from where an alternative design change is made and the trial moves on (Gavetti and Levinthal 2000). For a simple and decomposable problem, local trial-and-error search can generally lead to the global optima. However, on the more rugged, multi-peaked solution landscapes of high-interaction problems, a series of incremental changes of design choices is unlikely to result in the discovery of highly valuable solutions; instead, a trial-and-error search is often stuck in a "local peak" such that marginal change along any one choice dimension diminishes performance (Levinthal, 1997; Nickerson & Zenger, 2004).

A.2 Heuristic or Cognitive Search

Heuristic or cognitive search is another type of solution search mechanism in which the search is highly selective and is guided by various rules of thumb (heuristics) rather than relying solely on feedback from prior trials (H. A. Simon, 1988, 1990). The selection of a particular direction (region) of search is based on some cognitive map or implicit theory of how things work (Nickerson & Zenger, 2004). As pointed out by Gavetti and Levinthal (2000), such cognitive maps can be thought of as lower-dimension representations of higher-dimension landscapes. They lack the details but provide a rough reference of its topography which helps to increase the chance of discovering a high-value solution within reasonable time horizon. Surely, these cognitive maps are not static. As trials proceed, knowledge accumulates through feedback, managers can update their heuristics accordingly.

As noted by Nickerson and Zander (2004), heuristics can exist on two different levels: individual and collective. Heuristics exist on individual level in the forms of individual expert's skill stored in the individual memory. By searching one's memory for similar situations that match the situation one is confronted with and then taking appropriate actions, individual expertise can promote the rapid discovery of satisficing solutions (Simon, 1988). However, at individual level, human minds are constrained by the rate at which knowledge can be assimilated, accumulated, and applied (Simon 1945), the wide range of distinct knowledge sets needed for solving complex problems are most likely to be widely dispersed in the minds of many agents, each specializing in a unique knowledge domain. This means, heuristics in the collective form are more important for the solving of complex problems.

The formation of collective heuristics, however, is never easy. As individual beliefs are the basis of collective heuristics that guide search decisions, developing collective heuristics requires, in the first place, the sharing and exchange of knowledge among multiple agents to facilitate the formation of shared cognitive maps (Hsieh et al., 2007; Nickerson & Zenger, 2004). The sharing and exchange of knowledge, in turn, necessitates the development of a shared language to support communication (Arrow, 1974; Monteverde, 1995). Thirdly, the development of collective heuristics requires the reconciliation and coordination of the (honest) divergence in worldviews and beliefs, especially regarding the proper action to be taken (Fiol, 1994; Malmgren, 1961). Finally, given self-interestedness of agents, the collective heuristics are "negotiated beliefs" that are shaped not only by the quality of agents' logic, but also by each agent's self-interest and political position (James P. Walsh & Fahey, 1986).

B. The Match between Problem Types and Search Methods

In the previous subsection (4.4.2), we examine the dimensionalization of problems. As we have seen, the dimensionalization of problems is important because differences in problem complexity, decomposability and definiteness of problem structure pose different challenges for problem-solving. Our discussion on solution search further suggests that the two basic search methods can be easily matched to different problem types (see table 4-1).

For simple and decomposable problems, there is little interaction among knowledge sets; accordingly, the solution landscapes are relatively “smooth” (see figure 4-9). As suggested by the literature of systems theory and NK modelling, for these types of problems, local trial-and-error (directional) search through experiential learning and feedback provides certain advantages. In particular, for decomposable problems, solution search can be decomposed and *parallel search* (Nelson, 1961) can be implemented independently and simultaneously, which improves search speed (Sommer & Loch, 2004).

For complex problems, there are extensive interactions among knowledge sets and these interactions are often poorly understood. Consequently, the solution landscapes for such problems are more “rugged” (see figure 4-11). Due to the existence of pervasive interdependencies, they cannot practically be decomposed into sub-problems. For these types of problems, solution search is more difficult and local trial-and-error search is unlikely to discover the global optima. Existing literature indicates that for such complex, high-interaction and non-decomposable problems, cognitive (heuristic) search guided by some cognitive map or implicit theory may provide certain search performance advantages as it provides the basis to prioritize possible search directions and to evaluate the consequences of particular search decisions (Fleming & Sorenson, 2004; Gavetti & Levinthal, 2000; H. A. Simon, 1988, 1990).

Nearly decomposable problems benefit from both directional and heuristic search. Heuristic search defines the vicinity of potentially high-valued solutions, within which significant spatial autocorrelation and locational clustering of high-value resolution makes directional search highly efficient (Hsieh et al., 2007; Nickerson & Zenger, 2004).

Similarly, the distinction between ill-structured problems and well-structured problems suggests that different solution-search strategies realize performance advantages for problems of different structures, even though the distinction does not affect the topography of solution landscape. As mentioned above, the defining difference between ill-structured problems and well-structured problems is whether there is a consensus approach for solving the problems. For ill-structured problems, knowledge-set interactions are poorly understood, there is no widely accepted approach or formalized procedure for solving the problem. In this case, heuristic search could provide performance advantages via *ex ante* evaluations of the probable consequences of particular search decisions, as opposed to *ex post* reliance on feedback from previous trials (Fernandes & Simon, 1999; Gavetti & Levinthal, 2000). By contrast, for well-structured problems, the interactions among knowledge sets are well understood. The solution-search strategies for such problems are well-known and highly formalized, high-value solutions can be found with only practical amounts of independent search (H. A. Simon, 1973). For these problems, directional search guided by feedback or experiential learning provides certain efficiency advantages in achieving high-value solutions in comparison to heuristic search (Macher, 2006).

Table 4- 1: Matches between Problem Types and Search Methods

Search Method	**Problem Types**		
	Decomposability		
	Decomposable	***Nearly decomposable***	***Non-decomposable***
Directional search	++	+	0
Heuristic search	0	+	++
	Complexity (knowledge-set interaction)		
	Low interaction	***Moderate interaction***	***High-interaction***
Directional search	++	+	0
Heuristic search	0	+	++
	Definiteness of Problem Structure		
	Well-structured	***Moderately-structured***	***Ill-structured***
Directional search	++	+	0
Heuristic search	0	+	++

++: very effective; +: effective; 0: not effective

Source: Author's compilation from Table1, Nickerson & Zenger (2004: p. 621); Macher (2006); Leiblein & Macher (2009)

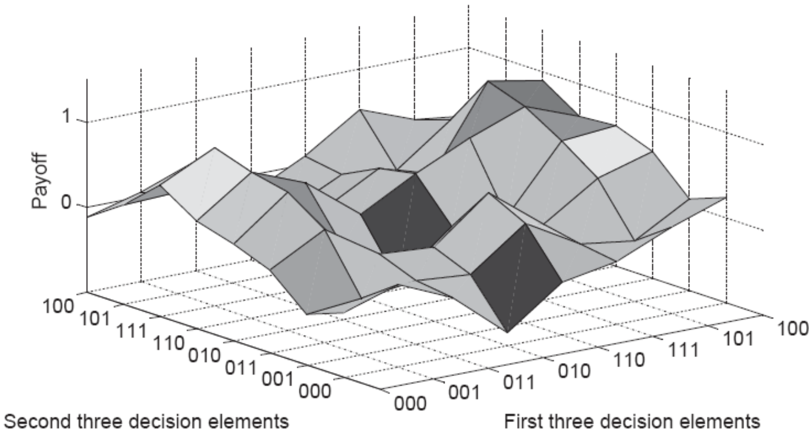

Figure 4- 8: Visualization[39] of NK Landscape
(N=6, K=2 with randomly distributed linkages)

Source: Fig 2, Ganco & Hoetker (2009)

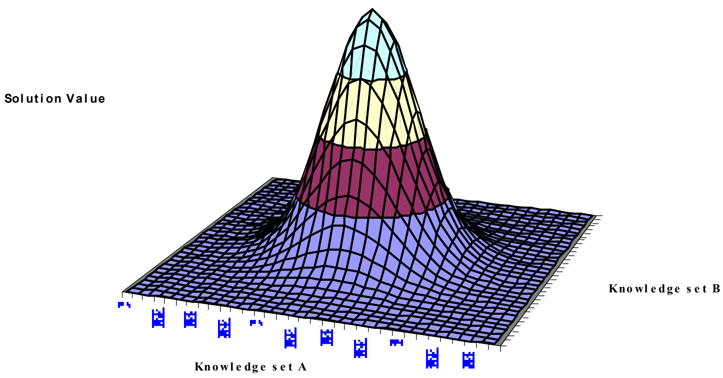

Figure 4- 9: Low complexity solution landscapes:
Decomposable problem

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[39] The N-dimensional binary space can be transformed into two-dimensional space in which each axis has N/2 points by simply ordering some of the neighbouring points along each axis (Rivkin & Siggelknow, 2007). By doing so, the actual NK solution landscape can be visualized as a 3-D space. Such visualization has some drawbacks (Ganco & Hoetker, 2009) as it reduces the local neighbourhood of each point from N (for N>4) to 4 which distorts the ruggedness of the space (where this distortion increases with N), making the visualized spaces more rugged than they actually are.

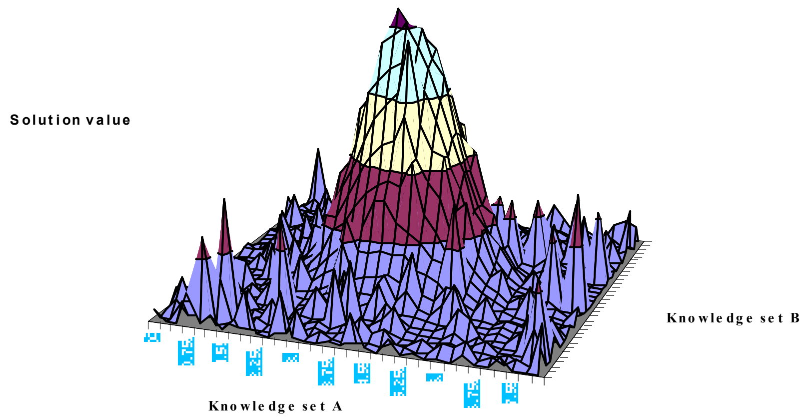


Figure 4- 10: Moderate complexity solution landscape: Nearly decomposable problem

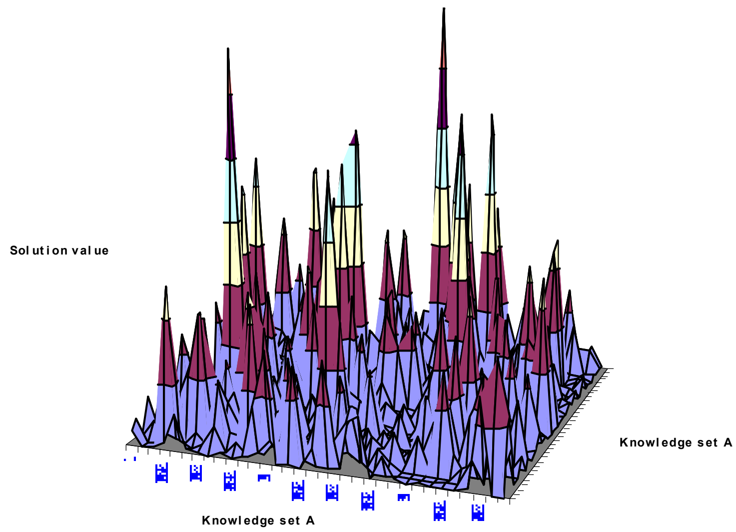


Figure 4- 11: High-complexity Solution Landscape: Non-decomposable Problem

Source: Nickerson (2005)

4.4.4 Challenges to Problem-Solving and Knowledge Formation

In the above discussion, we show that different problem types can be matched to different search methods in a way that realizes search performance. Once a valuable problem is chosen, the manager's task is then to identify the relevant knowledge sets, to select a search method appropriate for the chosen problem, and to craft a organization/governance mechanism that facilitates the implementation of the selected search method (Nickerson & Zenger, 2004). Given their nature, the solving of simple, low-interaction, decomposable and well-structured problems pose little challenge. By contrast, the solving of complex, high-interaction, non-decomposable and ill-structured problems requires extensive knowledge sharing and exchange among multiple agents which places considerable challenges in terms of cognitive coordination and incentive alignment given bounded rationality and self-interestedness of the agents.

A. Challenges to Cognitive Coordination

As mentioned above, at individual level, human minds are cognitively constrained in the speed with which they can assimilate, accumulate, and apply knowledge. Given this, it is unlikely that an individual has all the knowledge relevant to the solving of a highly complex problem. More often, relevant knowledge are widely distributed among multiple agents, each specializing in a unique domain of knowledge. Leaving aside the issue of incentive compatibility for the moment, to develop collective heuristics that guide solution search for complex problems, specialists' knowledge needs to be coordinated and aggregated. To that end, impediments resulting from ***heterogeneous information/knowledge*** and ***heterogeneous cognitive structure*** have to be overcome (Baer et al., 2012) [40].

Heterogeneity in information/knowledge sets suggests that although there may be some overlapping in the information/knowledge held by the members of a team (i.e., some information/knowledge is known to most or all members), each member also holds private information/knowledge (i.e., some information/knowledge is known only to a single member). As mentioned above, the formation of collective search heuristics necessitates the sharing and exchange of information/knowledge (Hsieh et al., 2007; Nickerson & Zenger, 2004). This in turn requires the development of high-bandwidth communication channels and shared communication codes (Arrow, 1975; Monteverde, 1995) such individually-held unique information/knowledge can be

[40] The theme of that paper is about the impediments to ***problem formulation*** (i.e., problem-finding) in a team with heterogeneous knowledge background. It seems obvious that these same impediments apply to problem-solving as well.

properly understood and correctly interpreted. Moreover, the psychology literature indicates that even if high bandwidth communication channels and shared communication codes are already in place, given bounded rationality, team members are still more likely to communicate with each other information/knowledge that incurs lower communicating and decoding costs, leaving unique, individually held information less likely to be communicated (Stasser & Titus, 1985, 1987), thereby potentially undermining the ability of the team to generate more effective search heuristics (Baer et al., 2012).

Impediment resulting from heterogeneous cognitive structure could be a more serious problem for the formation of collective search heuristics. By reason of bounded rationality, when confronted with a complex problem, individuals with different knowledge backgrounds tend to formulate search heuristic in a way that capitalizes on the knowledge they possess, resulting in the so called "tunnel vision" (Mason & Mitroff, 1981: p. 25). As a consequence, differences in cognitive structures are likely to produce insights that are at least partially contradictory with one another, triggering the emergence of "representational gaps" (Cronin & Weingart, 2007)—i.e., divergence in the understandings of a problem situation constructed on the basis of an individual's domain-related knowledge. Such gaps might jeopardize the formation of collective heuristic in two ways (Baer et al., 2012). In the first place, different representations or understandings of the problem involve different concepts, terminologies, and even different underlying assumptions, communication across these divides will be difficult and costly. To identify and to bridge the gaps, significant time and energy have to be invested in the persuasion of and the reconciliation with each other. Moreover, differences in cognitive structures and the resulting confusions and misunderstandings can promote conflict and distrust, which further impedes the sharing of knowledge and the formation of collective search heuristics.

B. Challenges to Incentive Alignment

In the above discussion, we assume away the issue of incentive compatibility to focus exclusively on the cognitive coordination aspect of the challenges. In the face of self-interestedness (of which opportunism is a special form), however, two hazards arise that plague efforts to support the knowledge sharing necessary for collective heuristic formation. As a result, cognitive coordination is compromised, and the issue of incentive compatibility becomes the central concern.

B.1 Knowledge Appropriation Hazard

Knowledge appropriation hazard arises directly from the well-known "fundamental paradox" in the knowledge acquisition (Arrow, 1962: p. 165): the value of knowledge to its potential acquirer is not known until it is revealed; however, once the knowledge is revealed, the potential acquirer has no need or at least less incentive to pay for it. Property rights and complicated contract design may provide some degree of protection in this circumstance; however, cognitive limitations, together with costly law enforcement, have made such contractual protections difficult to draft, hard to verify, and costly to implement. In other words, given the assumption of opportunism, the quasi public goods nature of knowledge/information (Shapiro & Varian, 1998) gives rise to knowledge appropriation hazards which in turn discourage knowledge sharing between parties with diverse and selfish interests. In particular, the risk of knowledge appropriation hazard, either in the form of unauthorized appropriation, or in the form of unintended leakage, becomes most pronounced in the case of inter-firm collaborations in problem-solving (A. P. Carter, 1989; Contractor & Ra, 2002; Kale, Singh, & Perlmutter, 2000; D. C. Mowery, J. Oxley, & B. Silverman, 1996a; Oxley, 1997; Oxley & Sampson, 2004). Overall, the knowledge-appropriation hazard has clear implications for the organization of problem-solving and solution search (Nickerson & Zenger, 2004): when the solving of a problem requires extensive knowledge sharing—as in the case of heuristic search that is appropriate for solving a complex problem—a governance structure that addresses this issue is much needed. By contrast, directional search requires little knowledge sharing, and it is not affected by the knowledge appropriation hazard.

B.2 Strategic Knowledge Accumulation Hazard

A second manifestation of the incentive compatibility issue relevant to problem-solving is that of strategic knowledge accumulation hazard (Nickerson et al., 2007; Nickerson & Zenger, 2004). According to Nickerson and Zanger (2004), strategic knowledge accumulation hazard arises as agents possess incentives to strategically alter the path of search and the heuristics that guide search. In particular, by strategically influencing the path of solution search in a way that enhances their specialized knowledge or that complements knowledge that they already possess, an agent can secure a stronger position to bargain for a larger portion of the value generated by a solution. Ultimately, the agent disproportionately benefits from the knowledge accumulation with respect to others, at the cost of distorting the cognitive maps, and diverting the search away from the optimal path. In short, absent governance remedies, problem-solving efforts that require heuristic search are likely to be jeopardized by such strategic knowledge accumulation hazards.

To sum up for the above discussion, given opportunism, problem solving efforts that require knowledge sharing and collective heuristics are plagued by two kinds of knowledge formation hazards, at the heart of which is the issue of incentive incompatibility. These two knowledge formation hazards tend to discourage knowledge sharing, distort cognitive maps, illicit conflicts regarding the proper ordering of trials, all of which diverts the search away from the optimal solution. As the problems become more complex, non-decomposable and ill-structured, these two hazards become more pronounced, efficient search then demands mechanisms that mitigate these knowledge formation hazards.

4.4.5 Discriminating Alignment

In the PSP literature, the discriminating alignment between problem/knowledge attributes and the few generic organizational modes was first proposed by Nickerson & Zenger (2004) and then refined and extended by a couple of other researchers (Heiman & Hurmelinna-Laukkanen, 2010; Hsieh et al., 2007; Leiblein & Macher, 2009; Macher, 2006). The underlying logic is straightforward: given that, (1) the magnitude and types of coordination and incentive challenge vary systematically across different problem types; (2) different search methods and different problem types can be matched in a way that realizes superior search performance; and that (3) the few generic organizational forms differ in terms of their costs and competencies in implementing different search methods; it follows that, (4) high value solutions to a particular type of problem may be best organized via some specific organizational mode—in other words, a discriminating alignment can be made that enables efficient solution search and maximizes expected values from solving the problem.

In the above subsections, we have demonstrated (1) and (2). In this subsection, we discuss (3) and (4).

A. Dimensionalizing the Few Generic Organizational Forms

Following Williamson (1991), Nickerson and Zenger (2004) contend that market and hierarchy differ fundamentally with respect to the dimensions of administrative command and control, incentive intensity, and dispute resolution mechanism. Meanwhile, they also incorporated insights from KBV to categorize organizational forms in terms of their different information transmission and coordination mechanisms (Leiblein & Macher, 2009).

These KBV insights fall into two categories. In the first category (Conner, 1991; Conner & Prahalad, 1996; Demsetz, 1988, 1995a), it is argued that compared with markets, hierarchies are characterized by authority relations and the exercise of direction. By having the less knowledgeable directed by the more knowledgeable in a hierarchical organization, direction provides "a low-cost method of communicating between specialists and the large number of persons who are either non-specialists or specialists in other fields" (Demsetz, 1988: p. 157). The second category of insights emphasizes that hierarchies are better able to develop high-bandwidth communication channels, specialized communication codes and a shared language (Arrow, 1974, 1975; Grant, 1996; Kogut & Zander, 1992, 1993, 1996; Monteverde, 1995), and to cultivate a shared identity (Ghoshal & Moran, 1996; Kogut & Zander, 1996; Nahapiet & Ghoshal, 1998), both of which facilitate the sharing and transfer of knowledge.

Nickerson and Zenger (2004) note that although both insights tend to support the efficiency of hierarchies in applying or transferring knowledge relative to markets, they refer to radically different mechanisms and their respective arguments are even contradictory with each other in some way. Specifically, in the first view (Conner, 1991; Conner & Prahalad, 1996; Demsetz, 1988, 1995a), hierarchies (firms) exist and realize performance advantages relative to markets by ***avoiding*** knowledge transfer; while in the second view, it is argued that firms exist instead to ***facilitate*** knowledge transfer, either through the development of high-bandwidth communication channels, specialized communication codes and a shared language (Arrow, 1974, 1975; Grant, 1996; Kogut & Zander, 1992, 1993, 1996; Monteverde, 1995), or through the formation of a shared identity (Ghoshal & Moran, 1996; Kogut & Zander, 1996; Nahapiet & Ghoshal, 1998) that "not only lowers the cost of communication but establishes explicit and tacit rules of coordination and influences the direction of search and learning" (Kogut & Zander, 1996: p. 503).

Based on these two distinct and competing representations of hierarchy within the KBV literature, Nickerson and Zenger (2004) differentiate hierarchy into two forms: authority-based and consensus-based hierarchy, each possessing a unique resolution to cope with coordinative and incentive challenges, and both supporting heuristic search more effectively than markets. Nonetheless, these two forms of hierarchy differ significantly in their supports of heuristic search, with one promoting knowledge transfer and the other essentially economizing on it.

Summing up, in their paper, Nickerson and Zenger (2004) introduce three archetypical organizational forms: market, authority-based hierarchy, and consensus-based hierarchy. Combining insights from both transaction cost economics and the knowledge-based view, they contend that as far as the costs and competencies for implementing solution searches (via different search methods) for different types of problem are concerned, these three organizational forms differ fundamentally in terms of the following three organizational features: (1) decision rights, administrative control and dispute resolution over the path of solution search; (2) communication channels and codes to support knowledge transfer, and (3) incentives to motivate solution search. Having identified these critical dimensions that differentiate the few generic organizational forms, they went on to develop an discriminating alignment between organizational forms and problem types—that is, to match the few generic forms and their different competencies in implementing directional or heuristic search to problem of different levels of complexity.

B. Discriminating alignment

B.1 Markets

For simple, decomposable and well-structured problems, the knowledge-set interactions are well-understood, the solution landscapes are smooth (Nickerson & Zenger, 2004) and the problem solving approaches are well-known (Macher, 2006). Directional search is the efficient method for discovering high-value solutions for these types of problems.

Due to their superior abilities to implement directional search, markets realize performance advantages in finding solutions to simple, decomposable (Nickerson & Zenger, 2004) and well-structured problems (Macher, 2006). Such abilities are supported by high-powered incentives, decentralized decision making, and mechanisms that allow individual agents to exploit and expand their own specialized knowledge. As indicated by Hayek (1945), in the market, price acts as a high-powered incentive that motivates agents to search for solutions that make optimal use of and enhance their specialized knowledge. Moreover, acute competitive pressures in market push agents to reduce organizational slack, to improve operational efficiency (D'Aveni & Ravenscraft, 1994), and to be more responsive in adapting to technical and environmental uncertainty (Williamson, 1985). Finally, when solving decomposable problems, economic agents can operate independently and simultaneously to speed up the searching process.

However, as problems become more complex, markets quickly fail because they do not have adequate coordination and administrative apparatuses to orchestrate the formation of collective heuristics. Even worse, given self-interestedness, markets simply exacerbate the knowledge formation hazards which contaminate efforts to support the formation of collective heuristics. In the first place, the markets' high-powered incentives discourage knowledge sharing and instead promote knowledge hoarding and misappropriation. Furthermore, these incentives also entice individual agents to strategically shape heuristics in ways that benefit them individually. In short, given the syndrome of features that define markets, markets are poorly suited for organizing the solution search for a complex, non-decomposable and ill-structured problem.

B.2 Authority-Based Hierarchy

Intermediate levels of problem complexity represent a nearly decomposable system in which sub-problems can be identified but non-trivial interdependencies among the sub-problems remain. Solution search for such problems requires some combination of directional and heuristic search.

Nickerson and Zenger (2004) argue that in the face of such problems, the logic of efficiency leads to the adoption of authority-based hierarchy. In this structure, there is an authoritative and knowledgeable central figure, who specializes in relevant knowledge domains and is capable of formulating suitable heuristics to guide search. Based on her understanding of the relevant critical knowledge interactions, this central figure decomposes the problem into sub-problems, to which some constraints (design rules) might be imposed. These sub-problems are then assigned to specialists within the firm, who search (mainly through directional search) within their knowledge domains for solutions. Once found, specialists' solutions to these sub-problems are transmitted vertically to the central figure, who aggregates them into a reasonably good solution to the original problem.

By having a knowledgeable central figure to exercise authority and to formulate search heuristics that prioritize the order of trials, "direction substitutes for education (that is, for the transfer of the knowledge itself)" (Demsetz, 1988: p. 157-158); authority-based hierarchy thus not only economizes on costly knowledge sharing and education, but also resolves efficiently knowledge formation hazards (by avoiding knowledge transfers), thereby realizing performance advantages in solving averagely complex, nearly decomposable, and moderately ill-structured problems relative to markets (Macher, 2006; Nickerson & Zenger, 2004).

Other features of authority-based hierarchy also facilitate centrally directed heuristic search, *though at the cost of dampening incentives for directional search*. Within the boundary of hierarchy, the contract law regime is that of "forbearance", by which the courts refuse to hear internal disputes over technical issues. Accordingly, "hierarchy is its own court of ultimate appeal" in most of the cases (Williamson, 1991: p. 274).

As noted by Nickerson and Zenger, "it is precisely this forbearance that grants authority within the bounds of hierarchy" (Nickerson & Zenger, 2004: p. 625).

Moreover, although the low power incentives tend to dampen motivation for autonomous knowledge accumulation, such a reduction in incentive intensity encourages the development of high band-width vertical communication channels and specialized codes that lower the costs of assimilating, accumulating, and applying knowledge for the central authority.

Nevertheless, an authority's direction is only valuable when the presence of such direction realizes superior search performance than its absense. As problems become more complex, the cognitive capacity of a single individual to assimilate relevant knowledge and to formulate search heuristics reaches its limits; consequently, authority-based hierarchies diminish in efficacy rapidly (Hayek, 1945)[41]. In other words, if the solving of a complex problem dictates such extensive combinations of knowledge that any single mind is incapable of integrating all the relevant knowledge in a timely fashion, it is quite unlikely that an authority is well suited to direct the solution search. For highly complex problems, the development of a collective search heuristic is required. In this regard, authority-based hierarchies are far less efficient than consensus-based hierarchies.

Similarly, due to the added costs to support the (unnecessary) vertical communication channels and codes, the low-power incentives that dampen motivation for directional search and knowledge accumulation, and the bureaucratic features of hierarchies, the effectiveness of authority-based hierarchy relative to markets also diminishes rapidly as problems become more decomposable.

B.3 Consensus-Based Hierarchy

Above, it has been argued that as problems become more complex, ill-structured and non-decomposable, the cognitive capacity of a single individual to assimilate relevant knowledge and to formulate an effective search heuristic reaches its limits, so that authority-based hierarchy begins to fail. For highly complex problems, the crafting of an effective search heuristic necessitates the sharing and exchange of knowledge among multiple agents to facilitate the development of a shared cognitive map of the solution landscape. Consensus-based hierarchy is a potential solution to

[41] As early as 1945, Hayek noted that "we cannot expect that [the problem of coordinating knowledge] will be solved by first communicating all this knowledge to a central board which, after integrating *all* knowledge, issues its orders" (1945, p. 524, emphasis in original).

the failure of authority in governing the formation of collective heuristics as problems increase in complexity.

Specifically, consensus-based hierarchy is supported by a distinct configuration of features that facilitate extensive knowledge exchange and collective heuristic formation (Hsieh et al., 2007; Nickerson & Zenger, 2004). In his classic work *The Limits of Organization*, Arrow (1974) has noted that hierarchy possesses a distinct advantage over markets in facilitating knowledge transfer through ***high bandwidth information channels***, ***firm-specific language and shared identities***. Arrow contends that, on an individual level, the formation of firm-specific capital involves "learning the information channels within a firm and the codes for transmitting information through them" (1974: p. 56); in aggregate, the investments in the development of high bandwidth communication channels and shared communication codes represent "irreversible capital accumulation for the organization" which gives an organization its "distinct identities" (1974: p. 55). Kogut and Zander (1992, 1996) argue similarly that firms exist because "they provide a social community of voluntaristic action structured by organizing principles that are not reducible to individuals" (1992: p. 384), because coordination, communication, and learning "are situated not only physically in locality, but also mentally in an identity" (1996: p. 502). With the assistance of a set of "higher-order organizing principles of how to coordinate groups and transfer knowledge" (Kogut & Zander, 1992: p. 388), which includes, *inter alia*, "shared coding schemes", "values", "a shared language", "shared identity", etc. (Kogut & Zander, 1992, 1996), the communication costs within the firm are substantially lowered, rules of coordination are established, "varieties of functional expertise can be communicated and combined" (Kogut & Zander, 1992: p. 390) and the "direction of search and learning" is chosen collectively (Kogut & Zander, 1996: p. 503).

Incentives and dispute resolution mechanisms within consensus-based hierarchies are also configured to support knowledge transfer and consensus-based decision making[42] (Hsieh et al., 2007; Nickerson & Zenger, 2004). In terms of incentive

[42] In fact, there is a considerable literature that explores the process of consensus-based decision making in team-like organizations. For example, Lawrence and Lorsch (1967b) on "organic" organizational forms, Ouchi's (1980) discussion of "clan" organization, Williamson (1985) on "relational team", Foss (2003b) and Zenger (2002) on "internal hybrids", etc. In this stream of literature, it has been argued that consensus-based group decision processes are supported by strong lateral flows of information (Tushman & Nadler, 1978), and they follow the logic of equal voice of all team members (Carley, 1992), or so-called "democratic referenda" (Kollman, Miller, & Page, 1997). It has also been suggested that in such consensus-based decision making processes, those with different worldviews are able to identify each other, form an *ad hoc* group, exchange information, and reach a decision on behalf of the entire team via a vote count (Butler & Grahovac, 2012); and the

intensity, consensus-based hierarchies are characterized by very low-powered incentives which are intended to create an open atmosphere for knowledge sharing and to discourage self-interest seeking and other strategic behaviours. Contract law and the dispute resolution regime in a consensus-based hierarchy is still that of "forbearance", but the exercise of authority has been intentionally minimized[43]. Dispute resolution, and more generally, decision making in consensus-based hierarchy involves multiple agents collectively and collaboratively deciding a path, presumably by educating and convincing each other—a process mainly shaped by the quality of agents' logic. As Arrow (1974) observes, if agents within a team share "a sufficiently overriding commonly valued purpose" (pp. 69-70), and if knowledge sharing and transfer is easy and less expensive, consensus can effectively substitute for authority. Under these circumstances, each agent within the firm conceives of a desired decision based on his/her knowledge and interests. As interests are commonly shared, ideas and knowledge are actively exchanged, consensus is spontaneous (Nickerson & Zenger, 2004).

In short, it is suggested that the team-like organization with the features of being vertically integrated, investing in high bandwidth horizontal communication channels and specialized communication codes, furnishing with low-powered incentives, and using consensus for deciding the sequence of search trials, can more efficiently craft search heuristics and develop new knowledge for solving highly complex, non-decomposable and ill-structured problems compared to other forms of organization (Macher, 2006; Nickerson & Zenger, 2004).

However, investment in and maintenance of horizontal communication channels and specialized communication codes that support extreme levels of knowledge transfer make this mode of organization comparatively quite costly. As problems diminish in complexity, such investments become unwarranted. Moreover, the very low-powered incentives characteristic of this organizational mode also constrain agnets' motivation to develop specialized knowledge or actually engage in local trial-and-error search appropriate for less complex problems; more generally, incentive is

winning view tends to emerge once all alternatives have been considered (Priem, Harrison, & Muir, 1995).
This being said, it is still less clear how agents with different interests and cognitive structures realize certain creative, cognitive and other benefits allegedly accruing to the consensus-based team-like organization (e.g., Cohen & Bailey, 1997; Nonaka, 1994; Weick & Roberts, 1993).

[43] The function of authority in a consensus-based hierarchy is not to formulate search heuristics and to prioritize the order of trials; instead, its function is mainly to assemble experts with the relevant knowledge sets, to invest in socializing these experts with respect to a common goal and a shared identity, to invest in social structures that create high bandwidth communication channels and shared communication codes, and to build an organizational atmosphere that facilitates extensive knowledge sharing and the aggregation of observational and experiential fragments e

always an issue in any form of "team production" (Alchian & Demsetz, 1972; Olson, 1965). Finally, the shared identity and strong social attachment associated with consensus-based hierarchy are not only costly to maintain, but they may in some cases misguide the process of search, reducing the firm's exposure to new ideas (Adler & Kwon, 2002; Smith-Doerr & Powell, 2010).

Above, three generic organizational modes (markets, authority-based hierarchies and consensus-based hierarchies) and their suitability for solving problems with different attributes are examined; a discriminating alignment is then spelled out (see table 4-2). Briefly, the discriminating alignment indicates that markets are most suited when problems are simple, decomposable and well-structured; consensus-based hierarchy entails high organizational costs and should only be adopted when the benefits for building consensus and forming collective heuristics are high, which is the case for problems that are highly complex, non-decomposable and ill-structured; finally, authority-based hierarchy is superior to markets in supporting heuristic search, but inferior in supporting directional search, which is most suited for a range of problems that are averagely complex, nearly-decomposable and moderately ill-structured.

Table 4- 2: Discriminating Alignment between Problem Attributes and Alternative Organizational Modes

	Market	Hierarchy	
		Authority-based Hierarchy	**Consensus-based Hierarchy**
Instruments			
Incentive intensity	++	+	0
Communication channels and codes to support knowledge transfer	0	+ communications are mainly vertical	++, communications are mainly lateral
Decision-making and dispute resolution	decentralized decision making; classical contract law	centralized, authority-based decision making; neoclassical contract law (forbearance)	consensus-based decision making; neoclassical contract law (forbearance)
Search			
Directional search	++	+	0
Heuristic search	0	+	++
Best Performance Problem Types			
Complexity (knowledge-set interaction)	Low interaction	Moderate-interaction	High-interaction
Decomposability	Decomposable	Nearly decomposable	Non-decomposable
Definiteness of problem structure	Well-structured	Moderately-structured	Ill-structured

++Strong; + semistrong; 0 weak

Source: Author's compilation from Table2, Nickerson & Zenger (2004: p. 626); Macher (2006); Leiblein & Macher (2009)

More intuitively, the discriminating alignment can be illustrated by figure 4-12 which compares the costs of organizing the problem solving under the three organizational alternatives for a range of problems that vary in the degree to which knowledge sets interact to define the solution landscape. The horizontal axis represents a continuous measure of the degree of knowledge-set interactions, holding the number of relevant knowledge sets constant (i.e., holding N constant and varying K in an NK system). The vertical axis represents the expected costs of finding a valuable solution. For a firm, the relevant question is to choose an organization mode that minimizes the organizational costs for a given problem.

In figure 4-12, all the three cost curves are upward sloping, suggesting that costs of organizing problem solving increase with complexity irrespective of organizational mode. For simple problems, markets provide high-power incentives, promote specialization and directional search. However, as the degree of knowledge-set interaction increases, the costs of organizing problem solving under market mode rises rapidly since this mode does not have adequate apparatuses to support heuristics formation and to cope with knowledge exchange hazards. By contrast, for low-interaction problems, the costs of organizing under authority-based hierarchy are higher than markets, reflecting the bureaucratic tendency of the hierarchy and the inability of authority to efficiently motivate knowledge specialization and directional search. As problems become increasingly complex, the costs of authority-based hierarchy rise less quickly (than markets), making it the efficient choice for dealing with moderate-interaction problems (between the points K_1 and K_2). Nonetheless, as the complexity of the problem continues to increase, authority-based hierarchy fails as the central authority does not have the capacity to assimilate all the relevant knowledge necessary for developing search heuristics for solving highly complex problems. The costs of consensus-based hierarchy are higher than the costs of authority-based hierarchy for problems with low and moderate levels of interaction as the operation of this mode requires costly investment to support extreme levels of knowledge sharing and consensus formation. Nonetheless, its costs increase less rapidly when it is used to organize highly complex problems, making it the economic choice for high-interaction problems (greater than K_2).

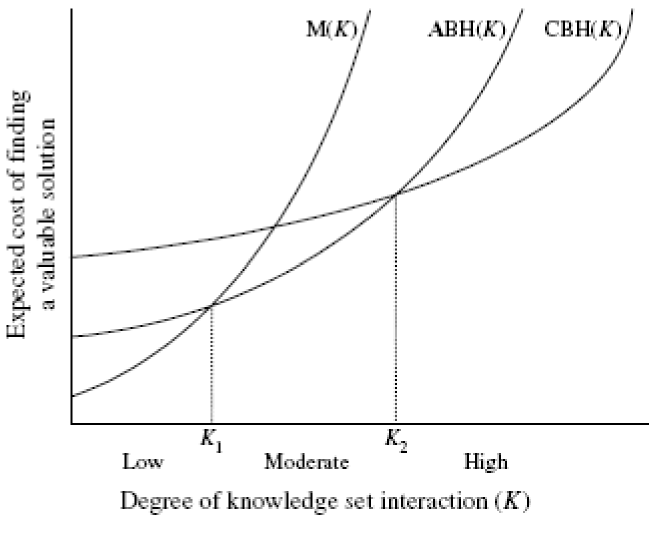


Figure 4- 12: Discriminating Alignment between Problem Complexity (knowledge-set Interaction) and Alternative Organizational Modes

Source: Figure 1, Nickerson (2004: p. 627)

4.4.6 Extensions

Above, we present the discriminating alignment between problem attributes and three generic organizational modes proposed by Nickerson and Zenger (2004) and Macher (2006).

A major drawback of the alignment is that by identifying the three generic organizational modes of market, authority-based hierarchy, and consensus-based hierarchy, this alignment in fact deals only with the make-or-buy decision. However, the choice of make or buy is but one of the many organizational choices. Other organizational modes, in particular the wide variety of inter-firm collaborative arrangements, are also relevant.

Combining insights from the problem-solving perspective and transaction cost economics, Heiman and Nickerson (2002, 2004) explored the governance implications of problem-solving complexity, knowledge tacitness and social dispersion in the context of inter-firm collaborations (i.e., alliances). They note that the mission of an inter-firm collaboration is often to create new knowledge by combining distinct knowledge sets, which are often tacit and distributed among multiple agents who are subject to cognitive limits in knowledge accumulation and application. As a result, the complexity of inter-firm collaborations tends to increase with the difficulties of working with and integrating distinct knowledge sets relevant for solving the problem and generating new knowledge. Heiman and Nickerson (2002, 2004) argue that of the two broad categories of alliance governance mode (i.e., the equity-based alliance and the contract-based alliance), the more hierarchical mode of the equity-based alliance is not only more efficient in facilitating knowledge transfer, but also more effective in mitigating the knowledge appropriation hazards resulting from increased knowledge transparency. With the assistance of a whole package of coordination, communication and administrative apparatuses, the equity-based alliance is a superior means for transferring/sharing tacit, socially distributed and complex knowledge, as the hierarchical structure is better able to accommodate high bandwidth communication, to cultivate the development of common communication codes, and to facilitate the formation of higher order organizing principles[44]. Meanwhile, it is also recognized that the adoption of the above measures

[44] To be more exact, to the two authors, high bandwidth communication channels and common communication codes are understood as sort of knowledge management practices (KMPs) which can be adopted irrespective of equity structure (i.e., can also be adopted/developed in a contract-based alliance, e.g., in the case of collocation of R&D teams from different firms). However, they recognize that given the assumption of opportunism, the deployment of KMPs increases the likelihood of choosing equity-based governance over non-equity based governance to safeguard against increased exposure to contracting hazards resulting from increased knowledge transparency.

gives rise to higher knowledge appropriation hazards via increased knowledge transparency, but the equity-based governance mode could, at the same time, provide better safeguards against misappropriation of knowledge as shared ownership tends to alleviate opportunistic incentives, increase monitoring and enhance managerial controls. In short, on the theoretical side, it is generally hypothesized that the higher the complexity and knowledge tacitness associated with collaborative activities, the more likely that the equity-based governance mode will be chosen (see Figure 4-13)[45].

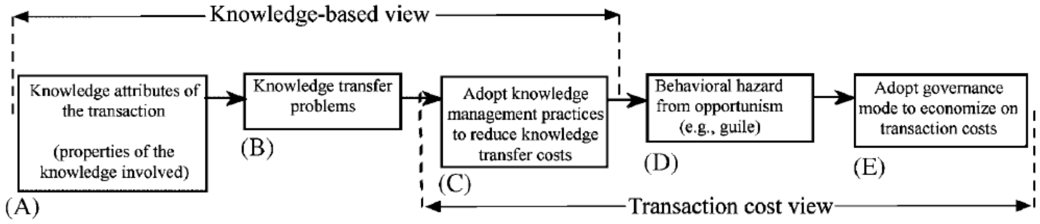


Figure 4- 13: Proposed Chain of Relationships

Source: Figure 1, Heiman & Nickerson (2004: p. 404)

Another theoretic extension in the same line is made by Leiblein, Macher and Ziedonis (2009), who tried to provide a finer differentiation of various mode of inter-firm collaborations and to disentangle their respective coordination and incentive capacities in the context of problem-solving. They note that knowledge creation and knowledge protection are the two aspects of the R&D alliance. On the one hand, to achieve success in collaborative technological developments, participating firms must be sufficiently open in sharing knowledge; on the other hand, to safeguard themselves against appropriation hazards, they must carefully control knowledge flows to avoid unintended leakage (Oxley & Sampson, 2004). Following Heiman and Nickerson (2004), they associate incentive alignment mainly with the adoption of common ownership, and coordination with the implementation of knowledge management practices (KMPs) such as collocation. They argue that through the

Briefly, it could be understood that higher complexity and knowledge tacitness tend to favour the choice of equity-based governance over non-equity-based governance.
To the current author, it seems perfectly reasonable to argue more directly that an equity-based organizational mode is more effective (than a non-equity based organizational mode) in implementing such knowledge management practices.

[45] More accurately, the whole proposed chain of relationships is as follows:
As the collaboration's knowledge attributes change from low to high levels of knowledge tacitness or problem-solving complexity, it is more likely that KMPs such as high-bandwidth communication channels and co-specialized communication codes will be adopted; the adoption of these KMPs, in turn, adds to the probability of choosing the equity-based organizational mode to protect against the increased exposure to contacting hazards.

choice of alliance forms that provide different combinations of ownership and collocation, a firm can balance between knowledge creation and protection. To be more exact, alliance arrangements that involve common ownership (i.e., equity Partnership or joint venture) are supposed to help align incentives, increase monitoring, and improve managerial control, while alliance arrangements that collocate personnel (i.e., co-development agreements or joint venture) improve coordination and communication between partner firms. A two-dimensional taxonomy is then developed, in which four types of alliance arrangements are identified—i.e., cash- & license-based, co-development, equity partnership, and joint venture, each with a distinct position in this two dimensional (common-ownership and collocation) space (see figure 4-14). Drawing on the logic of both TCE and KBV (to which the PSP belongs), they formulate hypotheses regarding the exchange- and firm-level factors that favour the choice of one (or more) of these alliance arrangements, as well as the performance consequences of such choices. In particular, in line with the fundamental logic of the problem solving perspective, it is argued that the major challenge of higher complexity in technological collaborations is on the coordination side rather than on the incentive side; therefore, it is suggested that alliance arrangements involving greater collocation (e.g., co-development agreements or joint venture) are more likely to be chosen as alliance complexity increases, and such choices realize superior technological performance.

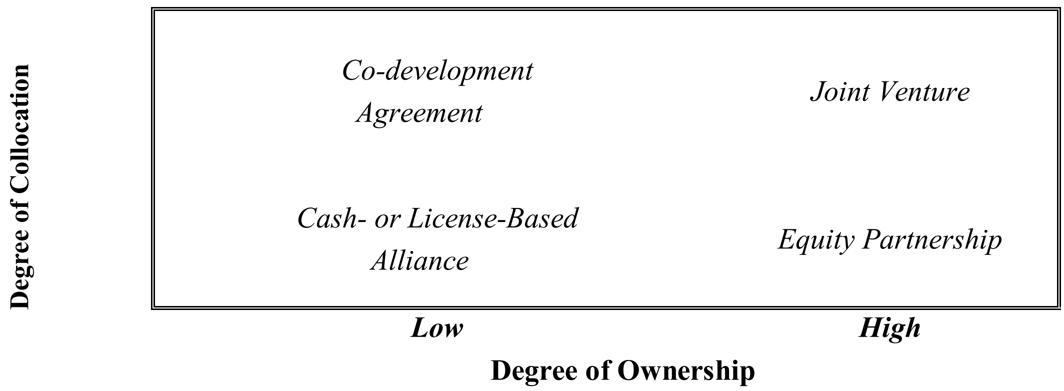


Figure 4- 14: A Two-dimensional Taxonomy of Alliance Arrangements

Source: Figure 1, Leiblein, Macher & Ziedonis (2009)

The above two contributions extend the problem solving perspective to the context of inter-firm collaborations. However, one should note that the discussion deal only with the choice between alternative collaborative arrangements, and it is still not clear how problem solving complexity might affect the choice between these collaborative arrangements and other organizational modes. In particular, if the choice is to be made between in-house and alliance, will a higher problem solving complexity favour the choice of in-house or *vice versa*? Leiblein and Macher (2009) briefly discuss this problem. Following the view of standard TCE (Williamson, 1985b, 1991) that collaborative arrangements (alliances) are hybrid modes of organization lying somewhere between the polar modes of arm's length market contract and hierarchy along a hypothetical continuum, they propose that these collaborative arrangements, and in particular joint ventures, are better able than markets in solving increasingly ill-structured or complex problems, but perhaps they are not suitable for the "most" ill-structured or complex problems in comparison to hierarchies. In other words, for averagely complex, nearly-decomposable and moderately ill-structured problems, particular hybrid (alliance) arrangements might realize performance advantages in finding high-value solutions compared with either markets or hierarchies, given the features (i.e., levels of incentive intensity, control, and coordination) available in these organizational modes.

4.5 Discussion

In the previous sections, we review in detail the basic framework of the problem solving perspective. We show that, borrowing insights from the theory of complex systems and the knowledge-based view, it has been identified in the PSP literature that the magnitude and type of coordination and incentive challenges to problem solving vary systematically with respect to some critical dimensions of problem attributes (i.e., knowledge-set interaction, decomposability and definiteness of problem structure) and knowledge characteristics (i.e., knowledge tacitness and social distribution). We also demonstrate that the insights of the *NK* modelling literature suggest that different search methods and different problem types can be matched in a way that realizes superior search performance. Furthermore, we illustrate that combining the insights of transaction cost economics and the knowledge-based view, it has been argued in the PSP literature that the few generic organizational forms differ in terms of their costs and competencies in implementing different search methods. Finally, we show that the PSP has worked out discriminating alignments that match problem types and organizational modes in a cost economizing manner (i.e., high value solutions search for a particular type of problem may be best organized via some specific organizational mode that maximizes expected values from the solving of the problem).

In this section, we proceed to identify gaps in the existing research and to propose a few promising directions for further work.

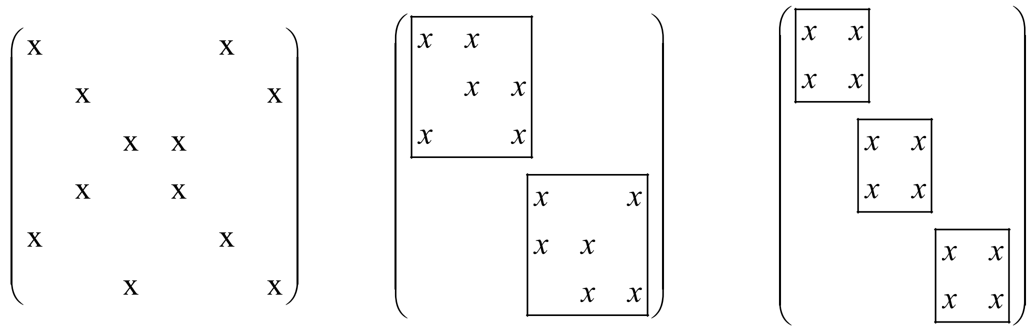
4.5.1 "Mutually Exclusive and Collectively Exhaustive Characterisations"

Above all, we concur with Leiblein and Macher's (2009: p. 114) general suggestion that productive future research may examine whether and to what extent the few particular dimensions that have been identified in the PSP literature "represent mutually exclusive and collectively exhaustive characterizations of environment and organizational form", and we can be more specific on this point.

A. Knowledge-set Interaction and Decomposability: One or Two Dimensions?

In the existing PSP literature, knowledge-set interaction and decomposability of the problem are not particularly differentiated; rather, they are often treated as two concomitant features along the same dimension. For example, in Nickerson & Zenger (2004), problems are classified into three categories: decomposable or low-interaction problems, non-decomposable or high-interaction problems, and nearly decomposable problems with moderate levels of knowledge interaction. In the few empirical studies (Leiblein et al., 2009; Macher, 2006; Macher & Boerner, 2012) expressly designed to examine the PSP hypothesis, knowledge-set interaction and decomposability are treated as a single variable, captured by the same measure (proxy). Clearly, these two dimensions are closely interrelated, as high interaction problems are certainly non-decomposable and low interaction problems are basically decomposable problems. However, knowledge interaction and decomposability are analytically distinguishable and they do not always change in the same direction. By definition (Nickerson & Zenger, 2004; H. A. Simon, 1962), knowledge-set interaction captures the intensity of interactions between relevant knowledge sets, while decomposability depends on the pattern of these interactions. A decomposable problem can be decomposed into sub-problems in such a way that the interactions among sub-problems are *negligible*; by contrast, for a non-decomposable problem, no matter how the problem is decomposed, the interactions among the "sub-problems" are *essential*; and for a nearly decomposable problem, the interactions among the sub-problems are *weak*, *but not negligible.* In short, decomposability indicates that "patterns of interactions among elements of a system are not diffuse but will tend to be tightly clustered into nearly isolated subsets of interactions" (Ethiraj & Levinthal, 2004a: p. 404).

The following three NK systems (see figure 4-15) might help to illustrate the difference between knowledge-set interaction and decomposability.



1. System 1 2. System 2 3. System 3

Figure 4- 15: The Interaction Matrixes of Three NK Systems (N=6, K=1) with Different Patterns of Decomposability

As all the three systems are characterized by *N*=6 and *K*=1, in each case, there are 12 interactions between the elements. Therefore, in terms of intensity of knowledge-set interactions, the three systems are equally complex. However, the three systems exhibit different patterns of decomposability.

In figure 4-15-1, the interactions between elements are random, and there is no obvious way to decompose the system into subsystems. By contrast, in figure 4-15-2, the system can be decomposed into two subsystems, and in figure 4-15-3, the system can be decomposed into three subsystems. Obviously, in terms of decomposability, system 1 is more complex than system 2 which in turn is more complex than system 3, but the three systems are equally complex in terms of the intensity of knowledge-set interactions.

B. Existing Knowledge-base: A Missing Dimension?

Above, we propose that knowledge-set interaction and decomposability should be treated as two distinct dimensions. A second and probably more substantial point to make is that a problem solver's existing knowledge base is a factor that has profound consequences for the organization and performance of problem solving, but its role has not been sufficiently discussed in the PSP literature.

In section 4.4.2, when we discuss the dimension of definiteness of problem structure, we have observed that the essence of the distinction made between ill- and well-structured problems is that the degree of problem complexity also depends on the extent to which the problem solvers know about (or are prepared for) the problem, as well-structured problems are outcomes of problem-defining processes.

Obviously, on a collective level, whether a problem is ill- or well-structured depends on how much human beings (as a whole) have known about the problem, and to what extent they have developed corresponding techniques for solving the problem. Likewise, on an individual level, the definiteness of problem structure depends on how much a solver is equipped with the relevant knowledge and techniques to solve the problem. For example, being a well known extremely ill-structured problem[46] that has confounded mathematicians since the 17^{th} century, the definiteness of the problem structure for "*Fermat's Last Theorem*" is in fact radically different for Andrew Wiles—who was knighted for finally providing a proof to this "deceptively simple to state" problem—and for a first year mathematics PhD student in number theory[47], or even for *Andrew Wiles* himself in 1980 (when he earned his doctorate from Oxford), 1986 (when he started working on the problem), 1993 (when he presented his first paper on the proof to the public which turned out to have contained a gap) and 1994 (when he finally circumvented the gap and thus completed the proof) (Singh, 1997).

In fact, it can be argued more generally that a given problem would pose radically different challenges to different problem solvers with distinct knowledge bases, which leads to different organizational choices and performances. Similar points have been made by Macher and Boerner (2012) who contended that firms with more technological knowledge in relevant fields can improve performance not only via experiential learning by doing (which tend to favour the choice of internal development), but also through better supplier relationship management (which instead tends to favour the choice of markets). Therefore, a firm's technological knowledge base is "likely to have organization and performance implications that

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[46] As explained by Fernando Q. Gouvêa (chair of the department of mathematics and computer science at Colby College) in a Scientific American (1999) article, Fermat's Last Theorem has been so difficult to prove because

> *"It is hard to connect the Last Theorem to other parts of mathematics, which means that powerful mathematical ideas can't necessarily be applied to it. In fact, if one looks at the history of the theorem, one sees that the biggest advances in working toward a proof have arisen when some connection to other mathematics was found. For example, Polish mathematician Ernst Eduard Kummer's work in the mid-19th century arises from connecting the Last Theorem to the theory of cyclotomic fields. And Wiles is no exception: his proof grows out of work by Frey, Serre and Ribet that connects Fermat's statement with the theory of elliptic curves. Once that connection was established, and one knew that proving the Modularity Conjecture for elliptic curves would yield a proof of Fermat's Last Theorem, there was reason to be hopeful. Wiles's work shows that such hope was justified."*

[47] It is suggested (Granville, 1993) that Wiles's proof is so complex that at the time when it was just published, "there are perhaps no more than half-a-dozen people in the world who are capable of fully understanding all the details of what Wiles has done". With the proliferation of the relevant knowledge, and in particular, with the publication of materials (e.g., Cornell et al., 1997) that aim at making the full range of required topics accessible to a wider audience of mathematicians, or even to "a graduate student in number theory" (Cornell et al., 1997), the number is certainly much larger by now.

depend in part on the structure of technological development" (Macher & Boerner, 2012: p. 3). To rephrase, a firm's existing knowledge is likely to have impacts on the organizational choice and the performance of the problem solving, both through its *independent effect*[48] and through its *interaction effect* with the structure of the problem. In the empirical setting of drug development in the pharmaceutical industry, their results suggest, *inter alia*, that by some measure of general knowledge stock[49] ("clinical patent"), a higher level of existing knowledge base tends to favour the choice of internal development over the market. In addition, a firm's existing knowledge base—either in terms of its specialized "technological area experience", or in terms of its general clinical patent stocks—is estimated to be an important driver of drug development performance. Finally and most interestingly, they examined the interactive effects that technological area experience and problem structure have on problem-solving organization and performance, and it is found that the negative effect of problem structure on drug development performance (measured by completion time) is moderated by pharmaceutical firms' therapeutic area experience for internal development, but not for outsourced drug development. In other words, the difficulties associated with developing and integrating knowledge across firm boundaries rather than within firm boundaries become especially acute when technological development problems are more ill-structured, as the relative performance of problem solving across firm boundaries vis-à-vis within firm boundaries becomes especially significant when technological development problems are sufficiently ill-structured.

A few points are noteworthy. First, we note that Macher and Boerner (2012) are agnostic as to whether a firm's existing knowledge base would have an independent impact on the organizational choice, and tend to believe that such an effect is neutral with respect to make-or-buy decisions, while we doubt whether such impact is really neutral. Second, they add to this stream of research by examining the interactive effects that a firm's existing knowledge base and problem attributes have on problem-solving organization and performance, but only the interaction effect between knowledge base and problem structure is examined. However, it seems quite

[48] The authors are somewhat ambiguous about the impact of a firm's existing knowledge base on its organization choice. Overall, their stance is that experience "helps firms build capabilities that provide performance benefits both in developing knowledge within and integrating knowledge across organizational boundaries" (Macher & Boerner, 2012: p. 16); therefore, firms with a higher level of knowledge have greater organizational options or flexibility in technological development. In short, although they are agnostic as to the organizational implication of greater experience, they do expect more experienced firms will achieve superior performance in comparison to less experienced firms irrespective of organizational mode.

[49] It seems that the two authors didn't note that "clinical patent" could be interpreted as a measure of a firm's general knowledge stock.

plausible that similar interaction effects might exist between a firm's existing knowledge base and other problem attributes (e.g., intensity of knowledge–set interaction and decomposability). Surely, these two questions are ultimately empirical and can only be resolved through further empirical studies.

Apart from Macher and Boerner (2012), in the PSP literature, systematic discussions on the possible linkage between a firm's existing knowledge-base and its organizational choice of problem solving are still missing.

However, in the *organizational learning, theory of complex systems, knowledge-based view, and innovation literature*, a firm's existing knowledge base has been found to have profound organizational ramifications and has in some cases been linked to the organization of a firm's problem-solving activities (in particular, R&D activities).

Specifically, as also noted by Macher and Boerner (2012), in the knowledge-based view literature, the firm is described as a routine-based, history-dependent knowledge bearing social entity that adapts experimentally and incrementally to past experiences (March & Simon, 1958; Penrose, 1955). Existing knowledge-base provides the firm with more in place information filters (Arrow, 1974; Henderson, 1993; Henderson & Clark, 1990), absorptive capacity (W. M. Cohen & Levinthal, 1990), and routines (Nelson & Winter, 1982) that facilitate the integration of knowledge (Kogut & Zander, 1992, 1996) and improve problem solving or technological development efficiency in a specific technological area (Nelson & Winter, 1982). Therefore, firms with a higher level of existing knowledge base in relevant technological areas achieve superior performance in technological development, irrespective of the organizational modes taken (Macher & Boerner, 2006). More fundamentally, it is also argued that firms internalize activities in which they have greater production experience and/or superior capabilities, and outsource those in which they have inferior capabilities (Argyres, 1996: p. 131). If we apply the insight to the context of technological problem solving, it can be argued that a firm with a higher level of knowledge in relevant fields is more likely to organize problem-solving in-house rather than through markets[50].

[50] In fact, in a working version of Macher & Boerner (2011), they hypothesized that "firms with more technological area experience are more likely to internalize technological development", ceteris paribus.
As this hypothesis is not fully supported by the data, this hypothesis does not appear in the published version of the paper.

On the basis of these contributions (in particular, absorptive capacity and inter-organizational learning perspectives), some more recent studies have tried to establish a more direct link between a firm's existing knowledge base and its organizational choice of technological development/problem-solving, especially in the context of technological alliance.

In this regard, the distinction made between the breadth (diversity) and depth (richness) of a firm's knowledge base (Bierly & Chakrabarti, 1996; W. M. Cohen & Levinthal, 1990; Granstrand, Patel, & Pavitt, 1997; Prencipe, 2000; Turner, Bettis, & Burton, 2002; Wang & von Tunzelmann, 2000) is of particular relevance.

Specifically, the breadth of a firm's knowledge base is generally defined as the range of knowledge areas that a firm possesses (Brusoni, Criscuolo, & Geuna, 2005; George, Kotha, & Zheng, 2008; Wang & von Tunzelmann, 2000; Zhang, Baden-Fuller, & Mangematin, 2007; K. Z. Zhou & Li, 2011). A firm with a broad knowledge base is familiar with a wide range of technological areas, and is thus capable of implementing wide scope search, often over unconventional search pathways, to explore new technological territories (Kauffman et al., 2000; Rosenkopf & Nerkar, 2001), to identify novel or non-obvious associations between distant knowledge sets that produce high-value solutions (W. M. Cohen & Levinthal, 1990; Henderson & Cockburn, 1994; Katila & Ahuja, 2002).

More dynamically, a firm with a diverse knowledge base is better able to keep track of the evolution of technological trajectories and to recognize new opportunities that deserve exploration (Dosi, 1982; George et al., 2008; Leiponen & Helfat, 2010). If a firm seeks to go beyond local search and innovate away from its current technological trajectory, it needs to span technological as well as organizational boundaries, and refer to external sources for knowledge and technologies beyond the technological domains of its current product offerings (Rosenkopf & Almeida, 2003; Rosenkopf & Nerkar, 2001). In this circumstance, a firm with a broader knowledge-base will have higher absorptive capacities (W. M. Cohen & Levinthal, 1989, 1990; Sampson, 2004b; Zhang et al., 2007), which would ease the process of the identification, assimilation and exploitation of knowledge from external sources by relating new knowledge (in particular, tacit and socially distributed knowledge) with its pre-existing knowledge-base (i.e., associative learning). Likewise, in an industry experiencing radical (architectural) technological innovation (Henderson & Clark, 1990; Langlois, 1988), knowledge and capabilities needed to realize such highly complex innovation are often dispersed across the whole industry, a diverse knowledge base would place a firm in a better position to build up system-level "architectural competence" or "integrative capability" by pulling together these dispersed knowledge/capabilities from various agents, and integrating them into a coherent whole (Henderson, 1994; Henderson & Cockburn, 1994; Leiponen & Helfat, 2010; Gary P. Pisano, 1994).

Finally, a firm with a diverse knowledge base is more likely to have superior "governance capability" (Argyres & Mayer, 2007; K. J. Mayer & Argyres, 2004; K. J. Mayer & Salomon, 2006) which enables it to effectively discern, evaluate and regulate their partner to secure its benefits (Arora & Gambardella, 1994; Reuer & Tong, 2005).

The breadth dimension captures the horizontal aspect (diversity) of a firm's knowledge base, whereas the depth dimension reflects the vertical aspect (richness) of a firm's knowledge stock within its core technological areas (Bierly & Chakrabarti, 1996). Specifically, the depth of a firm' knowledge base is usually defined as a firm's level of technological expertise in its core technological areas (George et al., 2008; Moorthy & Polley, 2010; Zhang & Baden-Fuller, 2010; K. Z. Zhou & Li, 2011). In the parlance of the theory of complexity and problem-solving (H. A. Simon, 1962), the depth of knowledge is concerned with the level of "analytical sophistication" of a specific subject, which "becomes complex because of the cognitive difficulty in pushing the particular matter to its logical extremes" (Wang & von Tunzelmann, 2000: p. 806).

The strategic importance of deep knowledge in a firm's core technological areas has been highlighted by many scholars (March, 1991; Nelson, 1982; Nelson & Winter, 1982). According to them, a firm's R&D is fundamentally a problem-solving process of searching among alternative pathways characterized by trial-and-error experimentation. A firm with deep knowledge in relevant fields will have a good understanding of the causal links within that niche—it knows what has worked (as well as not worked) in the past, and is more aware of the pitfalls over solution landscape. Accordingly, the firm is able to focus the search more finely, to decompose the problem into solvable sub-problems, to sequence the search in more efficient orders, and ultimately to improve its problem-solving efficiency for certain types of problems (Eisenhardt & Tabrizi, 1995; Nelson, 1982). Moreover, deep knowledge also allows a firm to exploit its technological expertise by making new combinations from old components, or by exploring new applications of the technology, as it understands the limitations of existing components from repeated use, and is able to identify and develop less apparent connections within the given sets of knowledge (George et al., 2008; Katila & Ahuja, 2002; March, 1991; Nerkar, 2003).

On the basis of the above ideas, some recent studies (Bonesso, Comacchio, & Pizzi, 2011; Zhang & Baden-Fuller, 2010; Zhang et al., 2007) have empirically examined the relationships between the breadth/depth of a firm's knowledge base, and its propensity to participate in an R&D alliance as well as its choice of alliance governance.

On the one hand, a broad knowledge base, by is nature, is systematic and socially complex, and is therefore hard to be imitated (Henderson & Clark, 1990; Henderson & Cockburn, 1994); on the other hand, a broad knowledge base also furnishes a firm with a strong absorptive capacity which enables it to learn at a faster rate than its partner in a learning race (Hamel, 1991). In other words, firms with a broad knowledge base face a lower risk that their knowledge will be appropriated by their partners, while their benefits from alliance participation are more certain and more likely to outweigh the costs. This tends to suggest, firms with a broad knowledge base have a stronger incentive to collaborate with partners to explore new technological opportunities. Accordingly, it is argued that the breadth of the technological knowledge base of a firm is positively related to its propensity for alliance participation (Zhang & Baden-Fuller, 2010; Zhang et al., 2007).

By contrast, the effect of deep knowledge is seemingly working in the opposite direction. Specifically, a well-established firm endowed with deep knowledge may stand to learn much less from its partner than its partner can learn from it (Ahuja, 2000; Hamel, Doz, & Prahalad, 1989; Khanna, Gulati, & Nohria, 1998; Larsson, Bengtsson, Henriksson, & Sparks, 1998), while sharing knowledge with partners can often lead to unintended knowledge leakage (Colombo, 2003; Oxley, 1997), undermining the firm's competitive advantage and industry position. Given the relatively high risks (especially in the form of "appropriability hazard") and the relatively limited benefits of alliance participation, it is argued that a firm with a deep technological knowledge base will have a lower propensity for alliance participation (Ahuja, 2000; Zhang & Baden-Fuller, 2010). At the same time, internal development or acquisition may often be a better option than alliance for such a firm (Rothaermel & Deeds, 2004).

On the empirical side, Zhang and her co-authors (Zhang & Baden-Fuller, 2010; Zhang et al., 2007) examine the above hypotheses in the setting of R&D alliances in the biotechnology sector, and the results are generally supportive.

Summing up, we contend that a firm's existing knowledge base has profound impacts not only on the performance, but also on the organization of its problem-solving activities, but this theme is not under-developed in the PSP literature. By contrast, in other related streams of literature, the same theme has been partially explored, both theoretically and empirically. Overall, these discussions and the limited empirical evidence tends to suggest, apart from its would-be interaction effect with other PSP variables (e.g., problem structure), a higher level of existing knowledge base tends to favour the choice of internal organization over markets in the face of make-or-buy decisions. In the context of alliance and with the breadth and depth of a firm's existing knowledge being differentiated, it has also been shown that a broader knowledge base adds to the probability of coming into alliances, whereas a deeper knowledge base works to contrary and tends to favour the choice of in-house if the choice is to be made between in-house and alliance. This being said, there are still considerable ambiguities with regard to the organizational consequences of a firm's existing knowledge base, especially when the choices are extended to a wider range of organizational forms—markets, various forms of alliance, and the hierarchy; and when its possible interaction effects with other variables (e.g., problem attributes and knowledge characteristics) are considered. For example, will a higher level of existing knowledge base in relevant fields favour the choice of in-house over alliance? Or when the choice is to be made between various alliance forms, will a higher knowledge-base favour a specific form of alliance? Given their different impacts on a firm's propensity for alliance participation, will the breadth and depth of a firm's existing knowledge base have different impacts on a firm's choice of alliance form, or more generally, on the organizational choice of its problem solving activities.

Still more questions can be raised if the effect of a firm's knowledge base is considered jointly with other variables, For example, if a problem is sufficiently complex that the breadth of knowledge that is required to solve the problem goes well beyond a firm's existing knowledge base, how will this firm organize the solving of this problem, how will problem attributes and knowledge characteristics interact with a firm's knowledge base and learning ability to determine its organizational choice and performance. Up to now, these are basically open questions.

4.5.2 Problem-Solving as a More General Framework: Possibility for Further Extension

In the previous subsection, we discuss whether and to what extent the few dimensions identified by PSP represent mutually exclusive and collectively exhaustive characterizations of problem solving context and organizational form. In particular, we propose that intensity of knowledge-set interaction and decomposability should be treated as two separate dimensions; and that a firm's existing knowledge base should be included as a critical variable in the PSP since it has profound implications for the organization and performance of a firm's problem solving activities, but its role has been largely neglected in the existing PSP literature.

A more general problem can be raised. That is, whether and to what extent, the PSP is, or can be extended to be a general framework for understanding economic organization and the boundaries of the firm. As has been shown above, in the existing literature, the problem-solving perspective has mainly been developed as a theory of the organization of *technological* problem solving (or R & D). In this story, new knowledge is generated by combining existing knowledge, and a high-value solution to a complex problem represents a novel combination (synthesis) of existing knowledge. However, knowledge is but one of the many resources that is needed for a firm's value creating activities, and R&D is only one of the many activities in a firm's value chain. One might wonder, apart from technological problem-solving, to what extent, the PSP can be applied to other non-R&D activities and be further developed into a more general framework for understanding economic organization.

It seems to the current author that the answer is quite positive, since the basic logic of PSP captures some very general aspects of a firm's value creating activities, and the unit of analysis (i.e., problem) makes it possible that the framework can be extended and applied to other non-R&D activities and be integrated with other streams of thought on economic organization. In particular, we see great opportunities if the problem solving perspective is joined by Porter's activity analysis (in particular, the value chain analysis) (Porter, 1985, 1991; Sheehan & Foss, 2009). Below, we would sketch out the basic elements of such an extension.

We note that in the KBV in general and the PSP in particular, a firm is viewed as a history-dependent bundle of physical and intangible resources, a routine-based, knowledge bearing and problem solving entity that adapts incrementally and experimentally to its past experience. As a producer, a resource combiner, the very general "problem" for the firm can be redefined generally as: (1) given its existing resources, capabilities and knowledge stock, how can a firm organize the discovery of a novel resource combination (in particular, a solution to a complex technological problem generated by synthesizing existing knowledge)—through a series of physical and cognitive acts, and following a set of often tacit problem solving procedures—that delivers a superior outcome and that potentially pushes outward the production possibility frontier (PPF); (2) once an novel resource combination (solution) is found, how can the firm organize the discovery, adjustment and management of a sustainable business model, by defining its positions along the value chain, and by combining resources (physical as well as intangible) across different stages of the value chain, to create and capture the inherent value of the found solution.

In the existing literature, the first problem has been discussed in detail, both in the context of research and development (Heiman & Hurmelinna-Laukkanen, 2010; Heiman et al., 2009; Leiblein et al., 2009; Macher, 2006; Macher & Boerner, 2012; Nickerson & Zenger, 2004), and in the context of production of complex products and systems (Dosi, Hobday, & Marengo, 2003; Prencipe, Davies, & Hobday, 2003), while the second problem has rarely been explored[51]. Here, we focus on the second problem.

As in technological problem solving, the search for and adjustment of a profitable "business model" (H. Chesbrough, 2010; H. Chesbrough & Rosenbloom, 2002)[52]—i.e., the way by which a firm specifies where and how it is positioned in the value chain (network) to create value and to generate revenue—can be thought of as a design problem, with each stage (component) of the value chain being its design element. For each of the design elements, there are multiple design choices[53]. For example, for a given valuable solution that has been found (which could often be embodied in a new product), the firm needs to identify its market segment (i.e., to whom the product is useful and for what purpose), to define the boundary and structure of the value chain (i.e., whether and how a specific stage/component of the value chain should be included), to choose an appropriate marketing strategy (e.g., mass marketing or niche marketing), and to organize the logistic network linking its supplier and customers, etc. As there are complex interactions between these different design choices, and the structure of interactions is often only partially understood (at least initially), the search for a profitable business model can be restructured as a solution search for a complex, ill-structured and non-decomposable design problem in a large combinatorial space of design choices. As indicated by the problem solving perspective, for such a problem, heuristic search is the appropriate

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[51] Chesbrough & Rosenbloom (2002) is an exception, Dosi, Hobday, & Marengo (2003) discusses some aspects of the problem.

[52] By the term "business model", it is meant the way by which a firm specifies where and how it is positioned in the value chain (network) to create value and to generate revenue. For a more detailed and operational definition, see Chesbrough & Rosenbloom (2002: p.533-534).

[53] More generally, the firm's positioning along the value chain (or in the value network)—i.e., whether or not the firm should include a specific stage in it value chain—can be also be viewed as a series of design choices.

search method, but the cognitive requirement for formulating "correct" search heuristics might go beyond the cognitive limit of any single individual. The solution search for such a problem thus necessitates the sharing and exchange of knowledge among multiple agents so as to facilitate the formation of shared cognitive maps and the development of collective heuristics that guide the direction of search, and a consensus-based hierarchy is supposed to be the most efficient mode for organizing search of this kind.

In the literature, in the context of the "production of complex products and systems" (Prencipe et al., 2003), it has been noted (Dosi, Hobday, Marengo, & Prencipe, 2003) that in the early stage of developing a new business model, a project-based, team-like and non-functional organizational structure is often adopted to coordinate the design choices characterised by poorly-understood strong interdependencies which create many local optima within the search space, particularly in the case of rapidly changing technological and market conditions, emerging properties and unclear user requirements. We note such a project-based, team-like and non-functional organizational structure is roughly in line with the so-called consensus based hierarchy.

Over time, as the interactions between different design elements across the value chain become increasingly well-understood and the design problem becomes less ill-structured, the new business model begins to take shape. Formal structure will then emerge and some sort of steady state problem decomposability becomes institutionalized, leading to the establishment of neat organizational structure (functional or business department or some sort of matrix structure, depending on the pattern of linkages between elements of the value chain) and the exploitation of economies of scale and scope. However, as noted by Dosi et al., (2003), even in a stable case, there are still many non-routine, complex activities (such as new product design, research and development, new marketing programmes and so on) within the firm that exhibit certain degrees of interdependency across different stages/components of the value chain which need to be closely coordinated. We note such a departmentalized hierarchical structure is roughly in line with the so called authority-based hierarchy which is alleged to be best suited for the solving of nearly-decomposable and moderately ill-structured problems.

Finally, as technology evolves, some parts of the value chain (value network) might become highly modularized and decomposable (Langlois, 2002, 2003b; Langlois & Robertson, 1992; Nickerson & Zenger, 2004; Sanchez & Mahoney, 1996), often as the result of the emergence of dominant design (Abernathy, 1978). In this case, vertical disintegration often takes place, and these parts of the value chain will no longer be organized within the firm but instead be organized through market interface.

Summing up, we contend that by joining with Porter's activity analysis [54] (in particular, the value chain analysis), the problem of a firm's organization of value creation can be posed as the following design problem: given a firm's pre-existing resources and knowledge, where and how should a firm position itself in the value chain to create value and to generate revenue?. Defining the "problem" in such a way, the problem solving perspective can be applied to non-R&D activities and be further extended to be a general framework for understanding economic organization that is applicable both to the analysis of intra-firm structure and to the analysis of the boundary between firms and the market. In this view, a firm's positioning within the value network, and accordingly its boundary, is shaped by the complexity, decomposability, and definiteness of the structure of the design problem described above. Overall, the intuition is quite similar to that derived from the NK-model literature—i.e., the structure of the organization should try to mirror the "true" structure of the underlying problem (in terms of the nature of interdependencies between its elements), so as to stimulate the development of desired interdependencies and to facilitate the solving of the problem, and in particular, the boundary of a firm can be seen as reflecting the overall patterns of decomposition of the design problem.

It also seems to us that such a view is roughly consistent with the empirical pattern of the evolution of organizational structure and the firm boundary over the industry life cycle reported by the existing literature (Argyres & Bigelow, 2010; Dosi, 1988; Freeman, 1982; Langlois, 1989a; Langlois & Robertson, 1989). That being said, the above discussion is but a rough sketch of the direction for future development, to realize the full potential of the problem solving perspective, more details need to be worked out.

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[54] The advantages of Porter's value-chain analysis are that it not only allows us to identify physically and technologically separable activities along a value chain (in our case, the design element of the problem), it also provides a powerful tool to look at the linkages both within (in terms of complementarity) and between value chains (in terms of commonality/similarity). In the existing literature (Kay, 1997; Rumelt, 1986), richness of resource linkages across value chains has been shown to be the key factor that explains the path-dependent way of a firm's expansion (diversification).

4.5.3 Are Alliances Really "Hybrid" Modes?

In section 4.4.6, we note that the problem-solving perspective has been applied to the choice of alliance governance. In particular, Leiblein and Macher (2009) propose a discriminating alignment that covers a more complete range of organizational forms—hierarchies, markets, and various types of alliance.

Following the view of standard TCE (Williamson, 1985b, 1991) that collaborative arrangements (alliances) are "hybrid" modes of organization lying somewhere between the polar modes of arm's length market contract and hierarchy along a hypothetical continuum, it is suggested (Leiblein & Macher, 2009) that these collaborative arrangements, and in particular joint ventures, are better than markets in solving increasingly ill-structured or complex problems, but perhaps they are not suitable for the "most" ill-structured or complex problems in comparison to hierarchies.

In our view, this argument is problematic. We doubt, as far as the costs and competencies of organizing different types of problem-solving are concerned, whether alliances are really "hybrid" modes of organization.

As has been indicated by various authors (e.g., Atik, 1995), these "middle case" organization modes are not blended cases, they are instead distinct types of organizational modes. Most notably, Kay (1992, 1997) argues forcefully that a joint venture is typically plagued by the problem of being the servant of two (or more) masters, which generates contractual, control and appropriability problems that all tend to exacerbate transaction costs relative to a pure hierarchical solution. In other words, a joint venture carries the burden of both hierarchical and market arrangements, making its transaction (coordination) costs greater than those of the corresponding pure forms. Much of the organizational and managerial literature also confirms that joint venture is often viewed by managers as the most expensive mode of organization, a last resort dominated by other modes of organization (for a 1980's view, see Berg, Duncan, & Friedman, 1982, for a recent view, see Brechbuhl, 2006). In short, it is misleading to treat alliance in general, and joint venture in particular (presumably the most important "hybrid" mode), as lying somewhere between the polar modes of arm's length market contract and hierarchy along some hypothetical spectrum, as it is asserted by the standard transaction cost interpretation (Williamson, 1985, 1990, 1991). Rather, they should be viewed as an independent category of organization mode. In terms of organization costs, joint venture might even be the most expensive mode of organization. Unless absolutely necessary—i.e, unless it could offer some sort of benefits that other organizational modes simply could not deliver—a firm would generally tend to avoid such "hybrid" forms (in particular, joint venture) of organization.

That being said, we also believe that alliances do offer some unique benefits—predominantly, access to complementary knowledge, especially in the face of solving a (non-decomposable) complex problem that goes beyond the existing capabilities/knowledge base of the firm. More specifically, as the problems to be solved become increasingly complex, the firm would certainly come to knowledge/capabilities bottlenecks at some point. Naturally, when solving such complex problems, the firm would have to refer to external sources for accessing complementary knowledge, most possibly by forming alliances with other firms (Coombs & Metcalfe, 2000; Grant & Baden-Fuller, 2004). Therefore, in the context of choosing between in-house and alliances, it is not unreasonable to argue that the more complex the problem is, the less likely the problem can be solved internally (for lack of complete knowledge); or equivalently, the more likely the problem-solving will be organized by alliance. We believe the above chains of argument are consistent with the logic of the knowledge-based view, although they are contrary to the "hybrid" view of alliances deeply held in the transaction cost economics. Ultimately, this is basically an empirical problem that can only be resolved through further empirical studies.

4.6 Conclusions

In this chapter, we review the existing problem solving literature, with the aim to present its basic insights, to demonstrate its substantial potential, to identify the gaps in existing research and to sketch out some directions for further developing this emerging perspective.

The chapter consists of five parts. In part one, we introduce the general background of the problem-solving perspective, highlighting its synthetic nature (trying to combine transaction costs economics, theory of complex systems, and knowledge-based view) and its exploration orientation. In part two, we argue that previous approaches in strategic management and economics organization are primarily concerned with value capture and value protection, while the vital role of value creation has largely been neglected. By contrast, the problem-solving perspective is characterized by a distinctive exploration orientation, and it can potentially offer a superior framework for addressing the issues of value creation and the organization of discovery. In part three, we offer a systematic review of the NK modelling literature and link it more closely with the problem-solving. Specifically, we introduce the basic elements and methods of the NK simulation, highlighting its advantages and shortcomings, and presenting the basic insights of recent economic and strategy applications of the NK model. In part 4, we review the core theory of problem-solving perspective, discussing in details a few critical aspects of its underlying logic. These critical aspects are: (1) to identify the few critical dimensions (problem types and knowledge characteristics) by which the magnitude and types of coordination and incentive challenges to problem solving vary systematically; (2) to demonstrate how different search methods (heuristic search or local trial-and-error search) and different problem types can be matched in a way that realizes superior search performance; (3) to show that the few generic organizational forms (market, alliances, authority-based hierarchy and consensus-based hierarchy) differ in terms of their costs and competencies (in terms of providing coordinative and incentive supports) in implementing different search methods, and finally (4) to work out the match between the few problem/knowledge attributes and the few generic organization modes—markets, hierarchies, and alliances—in an economizing manner that enables efficient solution search and maximizes expected values from the solving of the problem.

In part 5, we identify some non-trivial gaps in the theory of the problem solving perspective. We then sketch out some specific ways for fixing the problem and for further developing the problem solving perspective.

Specifically, on the basis of an extensive review of the whole PSP literature, (1) we argue that knowledge-set interaction and decomposability are two analytically distinguishable dimensions; accordingly, they should be treated as two separate variables; (2) with reference to some other closely related literature such as the knowledge-base view, organizational learning, and innovation etc, we contend that a firm's existing knowledge has profound impacts on the organization and performance of its problem solving activities, however, this dimension has been missing or at least has been seriously ignored in the existing PSP literature; (3) we note that the problem solving perspective has mainly been applied to the choices of make-or-buy, but less to other organizational choices (e.g., choice among various alliance forms, or the choice between in-house and alliance), and we doubt—as far as the governance of problem-solving is concerned—whether these alliance forms are really "hybrid" modes of organization; (4) we note that the problem solving perspective has been mainly applied to the organization of R&D activities (technological problem solving), we contend that once joined with by Porter's activity analysis (in particular, the value chain analysis), the PSP framework can be applied to other non-R&D activities and be further developed into a more general framework for understanding economic organization. We sketch out some specific ways for doing so.

Chapter 5: A Review of the Existing Empirical Literature Relevant to This Study

In this chapter, we review existing empirical evidence regarding the organizational implications of the few PSP (the problem-solving perspective) and KBV (the knowledge-based view) variables that have been included in our study. On the basis of the review, we will compare in the next chapter our main findings with those of relevant existing literature, and then draw the conclusions of this study.

In this study, a few TCE (transaction cost economics) variables have also been included; however, given that there have been several excellent surveys on the empirical transaction cost literature (David & Han, 2004; Geyskens, Steenkamp, & Kumar, 2006a; P. Klein, 2005; Lafontaine & Slade, 2007; Lajili, Madunic, & Mahoney, 2007; Macher & Richman, 2008; Masten, 2000; Masten & Saussier, 2002; Shelanski & Klein, 1995), we do not review empirical findings relevant to these few transaction cost variables. Interested readers are advised to refer to the articles listed above.

For the convenience of the discussion, variables are grouped into three categories: (1) those related to the problem complexity—i.e., problem structure, complexity, and decomposability; (2) those related to a firm's existing knowledge base—i.e., absolute and relative knowledge base, breadth and depth of knowledge base; and (3) those related to knowledge characteristics—i.e., tacitness and social distribution/embeddedness of knowledge. As the study is primarily inspired by the problem-solving perspective in the knowledge-based view, the review will focus on the problem-solving perspective literature. Admittedly, as an emerging perspective, very few empirical studies are expressly designed to examine the problem-solving perspective, so our review will extend into the background knowledge-based literature; whenever relevant, findings in the transaction cost economics literature will also be covered. For each variable, the organizational implications for the make-or-buy decision and for alliance governance will be discussed separately. Although the focus of the review is on empirical studies, to help understand the theoretic background, a short introduction on the relevant conceptual/theoretic framework will be presented whenever necessary.

Following the above guidelines, the literature review will be presented in four sections.

In section 1, we review the empirical findings regarding the governance implications of three variables that have been identified as characteristic of problem solving complexity—i.e., problem structure, problem complexity, and decomposability. As the theme of complexity has evolved along with the theory of the firm, our review will in fact cover three streams of literature: the problem-solving perspective, the knowledge-based view, and transaction costs economics[1].

In section 2, we discuss the empirical findings regarding how a firm's existing knowledge base—absolute and relative, depth and breadth—might affect its boundary choices. This section deals mainly with the knowledge-based view literature.

In section 3, we present the empirical evidence regarding the governance implications of two critical knowledge characteristics: tacitness and social distribution. This section draws mainly on the empirical knowledge-based view literature.

In section 4, we summarize key findings of our review.

5.1 Empirical Findings Regarding the Governance Implications of Problem Solving Complexity

This section deals mainly with the PSP literature but, whenever necessary, the review will extend into the background KBV literature.

5.1.1 In-house vs. Outsourcing (Make-or-Buy): The PSP and KBV literature

Before turning to a detailed review of the empirical literature, it is appropriate to reiterate briefly how problem-solving complexities (and a firm's existing knowledge base) [2] are related to the firm's make-or-buy choice in the problem-solving perspective.

In the knowledge-based view in general and the problem solving perspective in particular, the firm is described as a routine-based, history-dependent knowledge

[1] Whether an empirical study belongs to the problem-solving perspective, the knowledge-based view, or transaction costs economics is judged by its author(s) and by its hypotheses.

[2] Some of the very few PSP empirical studies we review examine simultaneously the governance implications of problem-solving complexity and those of a firm's existing knowledge base. For convenience of the discussion, we present the results of the two sets of variables jointly. We will also discuss briefly how a firm's knowledge base has been linked to its problems solving efficiency in the problem-solving perspective. In the next section, we will review the theoretical ideas regarding the governance implications of a firm's existing knowledge base in more detail.

bearing social entity that adapts experimentally and incrementally to past experience (March & Simon, 1958; Penrose, 1955). Existing knowledge-base provides the firm with more in place information filters (Arrow, 1974; Henderson, 1993; Henderson & Clark, 1990), absorptive capacity (W. M. Cohen & Levinthal, 1990), routines (Nelson & Winter, 1982) and heuristics (Nickerson & Zenger, 2004) that facilitate the integration of knowledge (Kogut & Zander, 1992, 1996) and improve problem solving efficiency in a specific technological area (Macher & Boerner, 2011; Nickerson & Zenger, 2004). A firm with a higher level of existing knowledge base within a technological area enjoys experiential learning-by-doing and uncertainty reduction performance advantages (Argote, 1999), and is more likely to keep technological development in-house, *ceteris paribus* (Macher & Boerner, 2011). Moreover, more experienced firms are also more capable of selecting, monitoring and learning from partner firms (W. M. Cohen & Levinthal, 1990; K. J. Mayer & Salomon, 2006). In short, firms with a higher level of existing knowledge base in relevant technological areas achieve superior performance in technological development, irrespective of the organizational modes taken (Macher & Boerner, 2006).

In addition, it has also been argued that the structure of problem has rich organizational and performance ramifications. Specifically, KBV proponents assert that hierarchies enjoy advantages over other modes of organization in organizing technological developments because they foster the formation of organization-specific communication codes, shared language and routines related to knowledge development and transfer (Grant, 1996; Kogut & Zander, 1992, 1996; Monteverde & Teece, 1982; Nelson & Winter, 1982). Building on these works, PSP theorists further develop a discriminating alignment that defines the match between problem complexity and organizational/governance modes. To be more exact, they argue[3] (H. W. Chesbrough & Kusunoki, 2001; H. W. Chesbrough & Teece, 1996; Heiman & Hurmelinna-Laukkanen, 2010; Heiman et al., 2009; Leiblein & Macher, 2009; Macher, 2006; Macher & Boerner, 2011; Nickerson & Zenger, 2004; Teece, 1996) that given the above-mentioned advantages, together with the control mechanisms and low-powered incentive characteristic of internal organization (Williamson, 1991), hierarchy are better able to implement heuristic search through information

[3] Earlier literatures, such as Teece (1996), Chesbrough & Teece (1996), do not use PSP terminology, however, the distinction they made between autonomous innovation and systemic innovation carries similar organizational and performance implications as does PSP. Specifically, the essence of their argument is that "autonomous innovations", which can be incorporated into an existing technical system without significant changes, is well-suited to be undertaken by specialized small firms; while "systemic innovation", which requires significant adjustments/adaptations in many different parts of the existing system, is better undertaken by a large, vertically integrated enterprise endowed with sufficient resources and capabilities.

dissemination, consensus building and authority direction as compared to market modes of organization. Therefore, when technological development involves ill-structured, complex or non-decomposable problems, hierarchies realize performance advantages. Market modes of organization, by contrast, enjoy certain advantages due to their more specialized expertise (Hayek, 1945), high-powered incentives, decentralized decision making (Williamson, 1991) and more direct competitive pressures (D'Aveni & Ravenscraft, 1994). Accordingly, market modes of organization improve both improve both the speed and quality of problem solving via directional search when technological development involves well-structured, simple or decomposable problems

Given the above short review of the theoretical links between the few PSP variables and the make-or-buy choice, we now turn to the empirical side to see to what extent these theoretic insights are empirically substantiated.

Two empirical papers can be found that apply the problem-solving perspective to the make-or-buy choice. Following a PSP reasoning, Macher (2006) examines the hypothesized links between problem attributes and governance choice in the context of semiconductor manufacturing process development. Macher includes two PSP variables—problem structure and problem complexity—as the key explanatory variables. Problem structure is operationalized by semiconductor product type[4], while problem complexity is operationalized by some measure of technological distance between the focal product and the leading edge product[5]. In a two-stage model using the Heckman switching regression technique (Heckman, 1976, 1979), Macher simultaneously examines the organizational and performance implications of the explanatory variables. In the first place, it is found that the more ill-structured and more complex the problem is, the more likely hierarchy will be chosen over

[4] According to Macher (2006), semiconductors are either analog or digital devices, and the latter can be further subdivided as either storage (e.g., memory) or function (e.g., logic) ICs (integrated circuits). The development of analog and memory products involves ill-structured problems, as the understanding of the parameter interdependencies between product design and process manufacturing is often incomplete, and the development of these two types of product is often described as based more on art than on science. The development of digital logic products, by contrast, deals mainly with well-structured problems and is assisted by the extensive use of EDA (Electronic Design Automation) tools.

[5] According to Macher (2006), process line-width is a well-accepted measure of technological sophistication for semiconductors as different generations of semiconductor technology have progressed along a well-defined trajectory of increasingly smaller line-widths. As leading-edge line-widths vary both over time and by product type, he uses some sort of relative measure to capture the degree of problem complexity for the development of each new manufacturing process. Specifically, it is defined as the leading-edge process line-width (at the start of the technological development under consideration) divided by the line-width for each new manufacturing process. Its value varies between 0 and 1. A value closer to 1 indicates that the development is closer to the technological frontier; accordingly, it involves a more complex problem.

market to organize the technological development. Moreover, it is also found that integrated semiconductor manufacturers (i.e., firms integrated in product design and semiconductor manufacturing) and specialized semiconductor manufacturers (i.e., firm specialized in semiconductor manufacturing) exhibit systematic performance differences when solving different types of technological development problems. Specifically, integrated manufacturers achieve performance advantages (in terms of speed and/or quality) when problem solving in technological development is ill-structured and complex; while specialized manufacturers (also known as foundries) realize performance advantages when problem solving in technological development involves well-structured and simple problems.

In a later study, Macher and Boerner (2011) use the same econometric techniques and a similar theoretical framework to examine how pharmaceutical firms organize their drug discoveries and developments. In this research, they include problem structure and a firm's existing knowledge-base (both specialized and general knowledge-base, which they call "technological area experience" and "general experience" respectively) [6] among the explanatory variables and explore empirically their organizational and performance ramifications. They differentiate two types of pharmaceutical firms—those integrated in drug discovery and drug development, and those concentrated in drug development (known as contract research organizations, CROs)—and use speed of technological development[7] (i.e. time to market) as the performance measure for the drug development.

In the first stage estimation, it is found that by the measure of "clinical patents"[8], firms with a higher general knowledge base [9] are more likely to internalize technological development, *ceteris paribus*; however, contrary to their expectation, firms with higher "technological area experience" or "general experience" do not differ from other firms in terms of their outsourcing decisions. As to the effect of

[6] "***Technological area experience***" is measured by the summation of prior successful drug development projects by the focal pharmaceutical firm in the relevant therapeutic area, adjusted by the time of their completion to allow for a heavier weight for more recent projects.
"***General experience***" is measured in a similar fashion, but over all therapeutic categories.
Apart from "general experience", other variables that are indicative of the firm's general knowledge stock have also been included, for example, the variable "***clinical patents***" measures the logged number of clinical patents by the focal pharmaceutical firm in the five years prior to the start of development.

[7] Specifically, it is defined as the calendar time for the drug to go through the clinical trial process, which begins with the start of Investigational New Drug (IND) submission and ends with the New Drug Application (NDA) submission.

[8] Cf. footnote 6. Accordingly to the authors, this variable is introduced as a control variable which "controls for pharmaceutical firms' ***knowledge stocks*** by separating the effects of technological area experience from some other knowledge-based measure that may also explain performance."(p. 10)

[9] It seems to the current author that "clinical patents" could well be treated as another measure of a firm's *general knowledge base* alongside with "general experience" defined in footnote 6.

problem complexity, it is similarly found that drug development that entails ill-structured problems is more likely to be conducted internally rather than through the market.

In the second stage estimation, they examine the performance impacts of these PSP variables. The results indicate that outsourcing helps the firms to improve performance when technological development entails well-structured problems, while internal drug development provides performance advantages vis-à-vis outsourced drug development for ill-structured problems. In addition, a firm's existing knowledge base—either in terms of its specialized "technological area experience", or in terms of its general clinical patent stocks—is estimated to be an important driver of drug development performance, irrespective of organizational modes. Finally, the results reveal an interesting interplay between the problem structure, a firm's existing technological base, and the choice of organization. To be more exact, it is found that the difficulties associated with developing and integrating knowledge across firm boundaries rather than within firm boundaries become especially acute when technological development problems are ill-structured, as the relative performance of solving problem across firm boundaries vis-à-vis within firm boundaries becomes especially significant when technological development problems are sufficiently ill-structured.

Summing up, it can be concluded that as far as the make-or-buy choice is concerned, the results of the two studies are rather supportive of the PSP predictions. At the same time, it is also fair to describe the empirical evidence as premature and highly limited. To develop the problem-solving perspective into a full-fledged theory, much more theoretical and empirical research is needed.

5.1.2 Alliance: The PSP and KBV literature

Apart from the make-or-buy decision, the problem solving perspective has also been applied to the analysis of alliance governance, and the underlying logic is rather similar to that for the choice between make and buy, but probably more synthetic in nature.

To be more exact, mainly following the knowledge-based view and the problem solving perspective, many scholars have explored the governance implications of complexity in the context of inter-firm collaboration, both theoretically and empirically (Contractor & Ra, 2002; Gulati & Singh, 1998; Heiman & Nickerson, 2002, 2004; Killing, 1988; Mesquita & Brush, 2008; Phene & Tallman, 2012; Simonin, 1999a, 1999b; White & Lui, 2005). In this branch of literature, it is generally proposed that higher complexity—as it is defined by Simon (1962) [10]—tends to favour the choice of the equity-based alliance. The most well-articulated argument in this line is probably the one developed by Heiman and Nickerson (2002, 2004). They note that the mission of an inter-firm collaboration is often to create new knowledge by combining distinct knowledge sets, which are dispersed among different agents who are subject to cognitive limits in knowledge accumulation and application. As a result, the complexity of inter-firm collaborations tends to increase with the difficulties of understanding and working with the distinct knowledge sets relevant for solving a problem and generating new knowledge; higher complexity, in turn, adds to the costs of organizing collaborations. Of the two broad categories of alliance governance mode (i.e., the equity-based alliance and the contract-based alliance), it is believed that the more hierarchical mode of the equity-based alliance is not only more efficient in relieving the knowledge transfer problems associated with complexity, but also more effective in mitigating the knowledge appropriation hazards resulting from increased knowledge transparency. To be more exact, it is argued that with the aid of a whole package of coordination, communication and administrative apparatuses, the equity-based alliance is a superior means for transferring/sharing complex knowledge[11], as the hierarchical structure is better able to accommodate high bandwidth communication, to cultivate the development of common communication codes, and to facilitate the formation of higher order organizing principles. Meanwhile, it is also recognized that the adoption of the above measures gives rise to higher knowledge appropriation hazards via increased knowledge transparency, but the equity-based governance mode could, at the same time, provide better safeguards against misappropriation of knowledge as shared ownership tends to alleviate opportunistic incentives, increase monitoring and enhance managerial controls. In short, on the theoretical side, it is generally hypothesized that the higher the complexity associated with collaborative activities, the more likely that the equity-based governance mode will be chosen.

On the empirical side, evidence is largely corroborative of the above hypothesis. Using the CATI database[12], Heiman and Nickerson (2004) examine empirically the

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[10] According to Simon, complexity refers to the extent of interaction between distinct sets of knowledge relevant for solving a problem.

[11] Surely, as noted by the two authors, high bandwidth communication and common communication codes can be understood as sort of knowledge management practices (KMPs), and can also be adopted/developed in a contract-based alliance (e.g., in the case of collocation of R&D teams from different firms). However, it is still reasonable to argue that an equity-based governance mode is at least more effective in implementing such knowledge management practices.

[12] The CATI (Cooperative Agreements and Technology Indicators) database on inter-firm collaborations is a relational database that documents cooperative agreements in multiple industries around the world. It is developed and maintained by Hagedoorn and other researchers at MERIT

effects of problem complexity on alliance governance choices. In that study, problem complexity is measured by a dummy variable indicating whether new, valuable, and strategic knowledge could be obtained by combining the distinct knowledge sets of the collaborators. The decision by firms is to choose between equity joint ventures and a wide range of non-equity governance modes for their collaborations[13]. In a sample that represents the population of publicly-announced alliances formed between 1977 and 1989, it is found that equity alliances are more likely to be chosen as problem solving complexity increases.

It should be noted that in the above discussion, an equity-based alliance is argued to be better able to cope with problems of complexity because it is superior both in terms of ***coordination*** capacities and ***incentive*** alignments. However, it is less clear which consideration (coordination vs. incentive) is likely to be dominant in the governance choice. Recent studies (Leiblein et al., 2009; Mesquita & Brush, 2008; Phene & Tallman, 2012) have tried to disentangle these two effects.

Of these few studies, the one by Phene and Tallman (2012) is probably the most interesting as it places the problem in the context of the more conventional choices of alliance type (equity-based vs. contract-based) and different levels of equity ownership. Specifically, it is argued that an equity-based arrangement is more effective in coordinating the collaborators in the face of complexity, as it creates a hierarchical structure furnished with a rich package of coordination, communication and administrative apparatuses (Gulati & Singh, 1998; March & Simon, 1958). Once the structure is set up, increasing equity share does not always offer increased coordination advantages (Kale & Puranam, 2004)—it simply adds to the authority and control of the focal firm, which might not necessarily be beneficial for mutual coordination. In short, Phene and Tallman argue that the coordination advantages of the equity-based arrangement should be attributed to the hierarchical structure itself, and not to the extent of the stake of the focal firm.

On the basis of the above arguments it is hypothesized that the equity-based governance mode is more likely to be chosen as the complexity of inter-firm collaborations tends to increase. To identify the relative importance of coordination and incentive concerns in shaping alliance governance choices, it is further hypothesized that if the coordination need is of primary concern in the face of complexity, the degree of complexity would not have an influence on the extent of

(Maastricht Economic Research Institute on Innovation and Technology), University of Maastricht. See Duysters and Hagedoorn (1993) for a detailed description.

[13] These unilateral non-equity governance modes include: customer-supplier partnerships, licensing, co-markship contracts and R&D contracts.

equity-investment by the focal firm. By contrast, if appropriation concerns dominate, a firm would not only adopt an equity-based arrangement, it would also take on greater equity investment to enhance control within the structure.

Using data compiled from the Securities and Data Company (SDC) Database on Joint Ventures and Strategic Alliances (Oxley & Sampson, 2004; Sampson, 2004a), Phene and Tallman (2012) test the above hypotheses. They differentiate two elements of complexity endogenous to the alliance: technological and strategic complexity. Technological complexity is concerned with the "nature of interaction required in inter-firm transfer of technology" (Phene & Tallman, 2012: p. 65-66). It is classified and measured as one of the following three categories: *no technological flows*, *unidirectional technological flows* and *multidirectional technological flows*. Strategic complexity, by contrast, encompasses the interdependence required in all other aspects of building and managing the alliance. The time frame of the alliance is used as its proxy. Based on whether it is formed for a specified period of time, each alliance is classified either as close-ended or open-ended. The former category is supposed to be strategically more complex than the latter one. The hypotheses are then tested separately in two datasets—first for the choice of alliance form with a set of 2442 contractual and equity-based biotechnology alliances formed between 1990 and 2009, and then for equity investment levels within a subset of the previous data comprising 413 equity-based alliances.

The results reveal several interesting findings. In the first instance, they find that different elements of complexity do not necessarily lead to a preference for the equity-based governance. To be more exact, it is found that—contrary to the prediction—technological complexity has a significant but ***negative*** effect on the choice of equity-based over contract-based governance. This means, technological complexity can be effectively managed under the auspices of a contractual arrangement, a more complicated equity-based arrangement is not necessary. Strategic complexity, on the other hand, behaves as predicted and has a significant positive influence on the choice of the equity-based governance.

Two comments can be made regarding the above results. Firstly, it is not a complete surprise that the two elements of complexity may have different governance implications, as some prior evidence also suggests that collaborations of pure technological activities not involving manufacturing, marketing and distribution are more likely to be organized through a contractual arrangement rather than an equity-based arrangement (Garcia-Canal, 1996; Gary P. Pisano, Russo, & Teece, 1988). Secondly, as noted by the two authors, the negative effect of technological complexity on the choice of equity-based governance should not be overstated as the results might be specific to this industry, in which strong intellectual property protection regimes make contractual arrangements tenable.

A second major finding of the study is that neither of the two elements of complexity has a significant effect on the extent of equity-based investment. This suggests that the adoption of equity-based governance in the face of complexity is mainly motivated by coordination rather than appropriation (incentive) concerns. Overall, this result tends to support the knowledge-based view rather than transaction costs economics.

Leiblein, Macher and Ziedonis's unpublished but already cited study (Leiblein et al., 2009) is broadly in the same line. Taking a similar stance as that of Heiman and Nickerson (2004), they associate incentive alignment with the adoption of common ownership, and coordination with the implementation of KMPs such as collocation. They note that knowledge creation and knowledge protection are the two aspects of the R&D alliance. On the one hand, to achieve technological developments success, firms in R&D alliances must maintain sufficient openness in the sharing of knowledge; on the other hand, to protect themselves against appropriation hazards, they must carefully control knowledge flows to avoid unintended leakage (Oxley & Sampson, 2004). Through the choice of alliance forms that provides different combinations of ownership and collocation, a firm manage to balance both considerations. Specifically, alliance arrangements that increase common ownership are supposed to help align incentives, increase monitoring, and improve managerial control, while alliance arrangements that collocate personnel improve coordination and communication between partner firms. A two-dimensional taxonomy is then developed, in which four alliance arrangements are identified—i.e., cash- & license-based, co-development, equity partnership, and joint venture, each with a distinct position in this two dimensional (common-ownership and collocation) space (see figure 5-1). Drawing on the logic of both TCE and KBV (to which the PSP belongs), they formulate hypotheses regarding the exchange- and firm-level factors that favour the choice of one (or more) of these alliance arrangements, as well as the performance consequences of such choices.

As far as the governance implications of complexity are concerned, the study follows unambiguously the PSP reasoning (Macher, 2006; Nickerson & Zenger, 2004). In the first place, following the spirit of prior PSP literature, the complexity of technological collaborations is measured by a composite index[14] of the problem

[14] They authors label it as "alliance difficulty".

structure and problem complexity related to the technological development efforts. In addition, in line with the basic logic of PSP, it is assumed that the major challenge of higher complexity in technological collaboration is on the coordination side rather than on the incentive side. Pulling together all the relevant arguments, it is hypothesized that alliance arrangements involving greater collocation (e.g., co-development agreements or joint ventures) are more likely to be chosen as alliance complexity increases, and such choices realize superior technological performance. Based on a sample of 664 technological development and production sourcing alliances in the semiconductor industry, and using a polychotomous two-stage estimation model, they test the above hypotheses. Their empirical results confirm that, *inter alia*, the "difficulty" of technological development problems determines both the selection and technological performance of alliance governance in a way that is consistent with the predictions.

Degree of Collocation		
High	*Co-development Agreement*	*Joint Venture*
Low	*Cash- or License-Based Alliance*	*Equity Partnership*
	Low	***High***
	Degree of Ownership	

Figure 5- 1: A Two-dimensional Taxonomy of Alliance Arrangements

The study by Mesquita and Brush (2008) aims similarly at untangling the safeguard and coordination effects of inter-firm governance mechanisms, but in their case, the problem is placed in a less conventional setting of governance decisions[15]. On the basis of a set of data collected by survey from 239 suppliers in the equipment industry, they develop and estimate a two-stage, dual performance model to examine separately the production and negotiation efficiencies[16] in the alliance-like long-term buyer-supplier relationships. They demonstrate that the relative extent of production

[15] The conventional governance decision in alliance literature is either to choose different alliance type (equity-based vs. contract-based), or to choose different level of equity ownership, while in the case of this study, the decision is about different combinations of formal contractual and informal relational governance mechanisms for long-term buyer-supplier relationships.

[16] According to the authors, production and negotiation efficiencies represent the coordination and safeguard aspect of governance mechanism respectively. To be more exact, the authors argue that the governance mechanism is chosen out of two interdependent yet different considerations (1) to "***safeguard*** owners of specialized assets from the losses, haggling, and negotiation inefficiencies resulting from exchanges with ***opportunistic*** partners" (Mesquita & Brush, 2008: p. 785), and/or (2) to improve "production coordination" of "handling of the organizational complexity inherent in decomposing production tasks and managing their interdependent parts across firms." (Mesquita & Brush, 2008: p. 785)

or negotiation efficiency gains of the inter-firm governance mechanism (compared with pure market governance), be it contractual or relational[17], depends on the relative levels of complexity and specificity. In other words, whether coordination or safeguard concerns become the dominant motivator for firms engaging in long-term buyer-supplier relationships is context-dependent. Specifically, it is found that in nonspecific but complex exchanges, inter-firm governance mechanisms operate mainly as coordination mechanisms—i.e., in this case, firms benefit from relational governance and contract completeness mostly for the production efficiencies improvements they enable; whereas in specific, noncomplex ones, they serve mainly as safeguard mechanisms, and the safeguard effect is significant only for relational governance.

Summing up, the above few empirical studies tend to suggest: the more ill-structured and the more complex an inter-firm collaboration is, the more likely that the equity-based alliance will be chosen to govern this collaboration. Moreover, it has also been shown that, in the face of complexity, the adoption of the equity-based governance is mainly motivated by concerns over coordination issues rather than incentive alignment. To put it somewhat differently, the empirical evidence indicates that the major challenge of greater complexity on the governance of collaboration is mainly about coordination, not incentive alignment. Obviously, this is supportive of the prediction of PSP rather than TCE.

5.1.3 Complexity in the TCE literature.

As mentioned above, the theme of complexity has evolved throughout the history of the theory of the firm. As early as the 1970s, complexity has been listed in the TCE literature as a key factor that affects economic organization (Williamson, 1975), and Herbert Simon (1962) is often cited as the intellectual origin of the underlying ideas. A connection could thus be established between the concept of complexity in TCE and PSP. However, as has been noted by many scholars (Langlois & Everett, 1992; Pessali, 2006; G. Slater & Spencer, 2000), in the TCE literature[18], complexity and uncertainty are often used interchangeably, and the distinction between complexity

[17] Under the formal contractual mechanisms, parties specify several verifiable contingencies for regulating their exchanges. The more explicit and detailed such specifications are, the more a contract is said to be complete, and accordingly, the more it helps protect exchanges. Such protection is possible (although not perfect) because, given the possibility of legal intervention, parties refrain from opportunism. Relational governance is defined as a set of informal norms, or codes of conduct that foster bilateral flexibility, solidarity, and information exchange. Such relational mechanisms are also alleged to serve the safeguard and coordination functions.

[18] For representative statements of relevant views, see Williamson (1975) and Tadelis & Williamson (2012).

and uncertainty does not seem to matter much as long as both lead to the consequence of contractual incompleteness. More recent literature (e.g., Tadelis, 2002; Tadelis & Williamson, 2012) goes even further as it tends to equate transactional complexity with contractual incompleteness [19] [20], treating it in juxtaposition with specificity as a major source of *ex post* transaction costs—i.e., specificity leads to *ex post* lock-in and hold-up problems, while complexity and contractual incompleteness result in *ex post* haggling and frictions. Apparently, such a treatment tends to conflate complexity and its consequence, making it distinct from the original meaning defined by Simon. Leaving aside the exact meaning of complexity and its difference with uncertainty, in the transaction costs literature, the prediction is rather standard—as transactional complexity (however defined) increases, contracts will be more incomplete, thereby posing greater contractual hazards; hierarchy is then more likely to be chosen as the governance mode (Grossman & Hart, 1986; Lajili et al., 2007; Tadelis & Williamson, 2012).

In terms of empirical corroboration, some highly influential empirical studies (Paul L Joskow, 1985; Masten, 1984; Masten et al., 1991; Monteverde, 1995; Monteverde & Teece, 1982; Sharon & Eppinger, 2001) are often cited to suggest that the empirical evidence is strongly supportive of the above prediction (Lafontaine & Slade, 2007; Lajili et al., 2007). However, one should probably be more cautious with such an assertion, as the term "complexity" could mean very different things in different settings. Specifically, as far as the meaning of complexity is concerned, three different circumstances can be identified among these most-cited studies.

In some cases, complexity is defined in a way that is broadly consistent with its original meaning given by Simon (1962), and is included as an explanatory variable for its own sake (rather than as a proxy for other variables). For example, in the context of the auto industry, Sharon and Eppinger (2001) examine the relationship between product complexity and the firms' sourcing decisions (internal production vs. external sourcing). Although they relate their study to the TCE literature, their definition of "product complexity" is very much in line with that of Simon's (1962, 1969). To be more exact, they suggest that product complexity could be observed from the following three dimensions (Sharon & Eppinger, 2001: p. 189): (1) the number of product components to specify and produce; (2) the extent of interactions

[19] To be more exact, in Tadelis's model, the level of a transaction's complexity is the (only) shifting parameter that determines the design completeness of a contract which in turn, affects both incentive schemes and integration decisions.

[20] Mayer (2009) observes similarly that in the empirical TCE literature, "contract 'complexity' and 'completeness' are often operationalized in the same way", so one major issue with this literature is that "these two concepts are often conflated."(Mayer, 2009: p. 227)

to manage between these components (parts coupling), and; (3) the degree of product novelty. Moreover, they also argue that variations in product complexity are driven by ***product design choices*** such as ***product architecture***, and the major challenges of greater complexity on the governance of transactions are mainly about coordination rather than incentive alignment. In retrospect, it is somewhat surprising to note that the above arguments clearly foretell the subsequent developments of the problem solving perspective (Leiblein & Macher, 2009; Macher, 2006; Nickerson et al., 2007; Nickerson & Zenger, 2004).

In the second instance, complexity is conceptualized roughly in line with Williamson and Tadelis. To be more exact, this conceptualization tends to ignore the difference between complexity and uncertainty, but it emphasizes complexity as being the cause of ***contractual incompleteness*** which in turn leads to haggling and frictions over *ex post* adaptations. Defined in such a way, complexity/uncertainty is either included as a variable in its own right, or as a proxy for contractual incompleteness. For example, in a study on the input procurement practices in the U.S. aerospace industry, Masten (1984) defines complexity in such a way that "the more complex a component, the more details to be accounted for and the more dimensions in which something can go wrong" (Masten, 1984: p. 409). He then uses it to capture "the degree of uncertainty on the production side" (Masten, 1984: p. 409) and measures it with a three-level ranking scheme developed by the company itself. Joskow (1985) and Masten et al. (1991) define and measure complexity in similar fashion, and these authors share the view that complexity and uncertainty exacerbates the hazards of contractual incompleteness, which leaves room for *ex post* opportunistic haggling over a favourable distribution of the gains from trade. In other words, in their view, the disturbances posed by greater complexity are mainly problems of incentive alignment rather than problems of coordination.

Finally, in the TCE literature, complexity—however defined—is often used as a proxy for other explanatory variables—most typically, for human asset specificity and physical asset specificity (David & Han, 2004). For example, in their highly cited paper on vertical integration in the U.S. automobile industry, Monteverde and Teece (1982) relate an automobile component's complexity to the amount of engineering effort that is required to design that component, and this construct ("engineering") is included not for complexity's own sake, but "as a proxy for transaction-specific skills" (Monteverde & Teece, 1982: p. 212)—that is, as a proxy for human-asset specificity. Similarly, Monteverde (1995) associates the complexity of technological problem solving with "the magnitude of necessary unstructured technical dialog between engineers" (Monteverde, 1995: p. 1629)—i.e., the necessary level of "unstructured, uncodifiable, generally verbal, and often face-to-face" (Monteverde, 1995: p. 1629) interpersonal communication between engineers from different functions. And such a construct is introduced not to capture the effect of the complexity[21], but to serve as a proxy for the utility of firm-specific "common organizational communication code"—or to be more exact, as a proxy for the "investment in specific human capital" (Monteverde, 1995: p.1636). Indeed, it has been noted on several occasions (David & Han, 2004; Lafontaine & Slade, 2007) that the commonly adopted proxies for human capital specificity often involve some measure of engineering design costs or efforts, and the same measure—interpreted in a slightly different way—can also be used as a proxy for complexity. This means, it is difficult to disentangle the effects of the two variables, and the same empirical evidence is often open to multiple explanations.

Summing up, although some recent reviews (Lafontaine & Slade, 2007; Lajili et al., 2007) on TCE literature suggest that the empirical evidence regarding the effect of complexity on governance choice is highly (if not overwhelmingly) corroborative of the transaction costs theory[22], other more systematic assessments reveal otherwise (David & Han, 2004; Krickx, 2000). Specifically, in a more narrowly-focused[23] review article, Krickx (2000) reports that when complexity is used as a proxy for uncertainty, complexity is not systematically related to vertical integration. David and Han's more comprehensive review, by contrast, reports that when complexity is used as a proxy for human *asset specificity*, *physical asset specificity* or *uncertainty*, the evidence is—at best—only weakly supportive of the TCE prediction[24] (David &

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[21] However, the author cautions that although the result of the paper is presented as supportive evidence for the asset-specificity hypothesis of vertical integration, the same result is not inconsistent with other efficiency-based approaches to firm boundaries (in fact, the knowledge-based view), such as Demetz's (1988) information economics-based explanation of vertical integration.

[22] Lafontaine and Slade (2007) review the results of 8 empirical studies and conclude that "***the evidence concerning complexity shows that, with one exception, its effect on vertical integration is both positive and significant***". Apart from the few most-cited studies mentioned above, the 8 empirical studies they list include a working paper by Hortacsu and Syverson (2007), and some papers published more recently (Woodruff, 2002; Forbes & Lederman, 2005; Gil, 2007; Acemoglu, Aghion, Griffith, and Zilibotti, 2010). Surely, the results of these studies, as a whole, are rather supportive of the transaction costs predictions. The problem is, under scrutiny, not all these papers they list could be comfortably classified as examining the effect of complexity on vertical integration (see table 6-2). In one of the cases (Hortacsu & Syverson, 2007), the authors do not include any measure of "complex inputs", as it is alleged; in two other cases (Woodruff, 2002; Acemoglu, Aghion, Griffith, and Zilibotti, 2010), the measures they list would better be viewed as proxies for specificity rather than for complexity. Given these flaws, the strength of their conclusion is somewhat impaired.

[23] The article reviews empirical evidence regarding the relationship between uncertainty and vertical integration.

[24] David and Han report that of the 37 tests that examine the impacts of human asset specificity, 5 used (firm-, product- or process-level) complexity as its proxy, of which 2 results (40%) are supportive of the TCE predictions, and none is counter to the theory; and of the 29 tests that examine the impacts of physical asset specificity, 4 use technological complexity as its proxy, only 1 result (25%) is supportive of the TCE prediction, and none is counter the theory; and finally, of the 87 tests

Han, 2004). Given the ambiguity surrounding the meaning of complexity, the diversity of its operational measures (cf. Lafontaine & Slade, 2007, Table 13), and the possibility of multiple explanations for the same empirical result, caution should probably be employed for the kind of over-optimistic or at least over-simplified conclusion. That being said, we still think it fair to conclude that, on an overall level and no matter how interpreted, the empirical evidence in the TCE literature leans toward a positive association between complexity and vertical integration.

Table 5- 1: Summary of the few more recent studies listed in Lafontaine and Slade (2007)

Study	Measure Employed	Variable Examined
Woodruff (2002)	Some dummies related to product heterogeneity	Specificity (risk of being held up resulting from relationship-specific investment)
Gil (2007)	Renegotiation frequency	Contractual complexity
Hortacsu & Syverson (2007)	***Does not include any measure of "complex input" as it is alleged***	***Complexity is not an explanatory variable***
Forbes & Lederman (2009)	Adverse weather conditions	Contractual complexity
Acemoglu, Griffith, Aghion, & Zilibotti (2010)	Technology intensity	Specificity (risk of being held-up resulting from relation-specific investment in R&D)

5.2 Empirical Findings Regarding the Governance Implications of the Firm's Existing Knowledge Base

5.2.1 In-house vs. outsourcing (Make-or-Buy)

In the previous section, we have seen that in the PSP literature, a firm's existing knowledge base has been linked to its problem-solving capacity and its boundary choices in technological development. In fact, those ideas are better understood as an extension of the basic knowledge-based arguments to the case of technological problem solving, and the underlying insights are mostly contributed by the KBV (or more generally, the knowledge-based and capability-based view) literature. As the

that examine the impacts of uncertainty, 2 use "component complexity" as its proxy, and none is significantly for or against the TCE prediction.

name of this literature suggests, a central aim of the knowledge-based/capability-based view of the firm is to inform how a firm's existing knowledge/capability base might affect its boundary choice, and it is generally held in the literature that ***firms internalize activities in which they have greater production experience and/or superior capabilities, and outsource those in which they have inferior capabilities*** (Argyres, 1996: p. 131).

Several empirical studies have tested the above hypothesis (Argyres, 1996; Bigelow & Argyres, 2008; Jacobides & Hitt, 2005; Madhok, 2002; Poppo & Zenger, 1998; Qian, Agarwal, & Hoetker, 2009; G. Walker & Weber, 1984) and the results are generally supportive (Qian, 2011).

Although titled "A Transaction Cost Approach to Make-or-Buy Decisions" (G. Walker & Weber, 1984), Walker and Weber's 1984 article is among the earliest empirical studies that examines the knowledge/capability-based hypothesis. Along with transaction costs variables, they include variables that capture the supplier's and the buyer's existing knowledge/capacity base. Specifically, among the three indicators[25] that measure "supplier production advantages", the indicator called "difference in manufacturing process" is seemingly defined to capture supplier's relative advantage in manufacturing process[26]. To account for the influence of buyer's capability on the level of "supplier production advantages", the variable "buyer experience" is also included, and it is indicated by "the degree of similarity between the tools and equipment required to manufacture the component and those the buyer already uses" and "the extent to which the buyer has strong expertise in the technology required to manufacture the component" (G. Walker & Weber, 1984: pp. 380-381). By estimating a structural equation model, they find that "comparative production costs"—as measured by supplier's production advantages—is the strongest predictor of make-or-buy decisions; "buyer experience", by contrast, is not significant for this choice; while the effects of transaction-costs factors, such as volume uncertainty and supplier competition, are statistically significant but substantively smaller.

Apart from contributing the articulated capability-based prediction on boundary determination of the firm[27], Argyres' (1996) in-depth case study also present some

[25] The other two are supplier's advantage in scale of operations, and estimated annual savings to make (as opposed to buy) a component.

[26] To be more exact, the indicator is defined as "the extent to which substantial differences in manufacturing processes for the component between outside supplier and the buyer favor the outside suppliers" (Walker & Weber, 1984: pp. 380).

[27] The Argyres's (1996: p. 131) original proposition is copied as follow:

qualitative evidence that is at least partly supportive the knowledge/capability-based view. In this study, Argyres simultaneously examines and compares the relative explanatory power of transaction costs and the knowledge/capability-based explanations for the make-or-buy decisions over a wide range of productive activities within a large firm. It is found that in some cases asset specificity alone is determinate, but in others capabilities or a combination of both considerations provide better explanations. Overall, neither transaction-costs nor capability-based considerations dominate the make-or-buy decision. What is particularly worth noting is that Argyres' analysis contributes valuable insights on the mechanisms through which capabilities shape the firm boundary. Specifically, the similarity of the knowledge bases between different activities, and the time required to acquire knowledge are identified as the critical mechanisms through which capabilities operate. In this view, the stable set of activities which the firm carries out is partly shaped by its past development rather than merely by economization on transaction costs. When the knowledge/capability required to perform a specific productive activity is either tacit or team-based which takes significant time to acquired, such knowledge/capability will have substantial boundary consequences. Finally, Argyres also indicates that the capability-based view should be understood as a dynamic rather than a static framework. For example, firms generally tend to outsource an activity if external suppliers have superior capabilities; however, if in-house development of capabilities is perceived to be value-creating in the long run, firms may choose to tolerate high in-house production costs in the short run, despite low transaction costs.

The evidence from the above two studies has been shown to be supportive for the knowledge/capability-based prediction of the boundary choice. However, in both cases, the analysis is based on data collected from a single firm, and the generality of their findings could be limited. More recent studies, by contrast, tend to use large sample, cross-sectional and longitudinal datasets, and have adopted more rigorous econometric techniques (e.g. Heckman two-stage estimation model that corrects for sample selection bias).

Leiblein and Miller's empirical study (2003) is based upon a cross-sectional dataset of 496 make-or-buy decisions involving 117 semiconductor firms. In this study, they use prior production experience in similar products using similar process technology as the proxy for the productive capabilities of a given firm. By estimating a series of

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"Proposition: Firms vertically integrate into those activities in which they have greater production experience and/or organizational skills (i.e., 'capabilities') than potential suppliers and outsource activities in which they have inferior capabilities, except in cases where explicit long-run decisions are taken to incur the costs of developing in-house capabilities. all else constant."

different logit models, they find that—alongside with others transaction cost variables (such as asset specificity, demand uncertainty and etc.)—firm-specific capabilities have a statistically significant effect on firms' vertical boundary choices. This result provides compelling evidence that a firm's past production experience is indicative of its current capabilities, which can be leveraged across similar value chain activities for its future boundary choices[28] (Argyres, 1996; Barney, 1999; Quinn; & Hilmer, 1994).

In the above few studies, the prototype of the hypotheses being tested is the one developed by Argyres (1996). Some researchers (Jacobides & Hitt, 2005; Jacobides & Winter, 2005) have criticised this type of hypothesis as being oversimplified. To address this problem, they have come up with a more nuanced hypothesis and have proposed for a better empirical design.

They reaffirm the simple observation that "the market" does not produce anything, it is but the thin interface through which products or services are exchanged; behind this thin interface lies another firm, a specialized production unit (Demsetz, 1995b). For market transactions to occur, both parties must find specialization advantageous, sufficiently so to outweigh any costs of trading; and this, in turn, implies particular properties about the distribution of productive capabilities in the industry. They suggest, to better understand the role of capabilities in shaping the boundary choice, it is necessary to look at the ***distribution of productive capabilities***. Although prior experience in relevant field is conductive to firm capability, it is not, by itself, an indication of comparative efficiency. To be more exact, even if a firm has accumulated substantial experience in relevant fields, as long as external suppliers enjoy comparative efficiency[29], the firm may choose to outsource. The outsourcing literature has provided many examples in this regard. Conversely, as has been similarly argued by Langlois (1992), even if a firm does not have much prior experience in carrying out an activity, it may still choose to internalize production if the capabilities of potential external suppliers are even poorer. On the basis of these observations, they develop a more nuanced set of hypotheses which incorporates an element of evolutionary selection. Specifically, together with the more familiar Argyres argument that "*superior productive capability in a particular vertical*

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[28] Basically, the argument is: a firm's capability at time *t* determines its boundary choice at time *t+1*.

[29] I intentionally choose not to use the term "comparative advantage" even if Jacobides and Hitt (2005) allege that their theory is a "comparative advantage" theory of vertical integration which "relies on comparative rather than absolute ('best in class") advantage" (Jacobides and Hitt, 2005: p. 1213). After a very careful reading of the paper, I find that the sort of "comparative advantage" they are talking about is clearly "absolute advantage" (better than some others in absolute term) rather than "comparative advantage" as it is defined by David Ricardo (1817) and known to trade theorists (Findlay, 1987).

segment will be positively associated with (the scale of) activity in that same vertical segment" (Jacobides & Hitt, 2005: p. 1213), they further hypothesize that, in a simplified two segments setting "*superior productive capability in a particular vertical segment will be negatively associated with integration" in its vertically adjacent segment* (Jacobides & Hitt, 2005: p. 1213). Summing up, what they propose is an improved empirical design that focuses more on the industry-wide distribution of capabilities (in particular, the distribution of productive capabilities along different parts of the value chain) and that uses better proxies to capture firm-specific capability more effectively.

Following these ideas and using highly-detailed, wide-coverage[30] and segment-based data[31] from the mortgage banking industry, Jacobides and Hitt (2005)[32] empirically test the above capability-based hypotheses in conjunction with a competing TCE hypothesis. They focus on two vertically linked segments in mortgage industry: loan origination and loan warehousing. They take the perspective of all banks that warehouse a loan, and then examine the make-or-buy decision across the interfaces of the two segments—that is, whether mortgage banks integrate into the segment of loan origination to "make" their own loan, or whether they "buy" it from another entity (e.g., another bank or a loan broker), or use a mixed mode (both making and buying). The dependent variable is thus a mortgage bank's "integration in retail loan production"; or more specifically, the percentage of total loans produced through a bank's own retail branches. Using labor productivity (output per labor input) and operating margin (revenue less total cost) as proxies for the firm's capabilities, they finds that both of the hypotheses are very strongly supported. And the conclusion is valid either in the OLS model that uses a continuous measure of integration as the dependent variable, or in the logit model where the dependent variable is treated as a binary choice of make-or-buy (using some cut-off point). To be more exact, it is shown that firms with higher productive capability in the segment of loan origination tend to be more integrated in this segment, while the coefficient of the efficiency in

[30] It is reported that the banks in their dataset are responsible for about 25 percent of the total mortgage loans produced in the United States; therefore, the samples are highly representative.
[31] Their data contains very detailed information along the whole chain of the production process, which enables measures of productive capabilities by value chain segment.
[32] Undoubtedly, the two authors are right in highlighting the importance of capability distribution (along the value chain) in understanding the firms' boundary choices, but it might be going too far for them to allege that their study contribute to—both theoretically and empirically—a "'comparative advantage' theory of vertical scope"(Jacobides & Hitt, 2005: p. 1212) that is to be distinguished from the "absolute advantage" or "unique, rare resource" view of vertical integration (Jacobides & Hitt, 2005: p. 1215). For one thing, their measures of productive capabilities, although detailed enough to cover each segment of the whole value chain, are actually rather similar to those used in Leiblein and Miller (2003); in both cases, what is captured is the absolute rather than comparative advantage of the focal firm, unless the term "comparative advantage" is otherwise defined.

the downstream segment of loan warehousing is strongly and negatively associated with integration in the upstream segment of loan origination. By contrast, the hypotheses on the role of transaction-costs receives only mixed support, and they conclude that the role of capabilities appear to be more important than that of transaction costs (Jacobides & Hitt 2005: p. 1210).

Adopting a similar research design that takes account of the industry-wide distribution of capabilities, Hoetker (2005) examines notebook manufacturers' sourcing decisions for innovative flat-panel displays. Specifically, by grouping together a firm's internal supplier with other external suppliers, the "make" choice is treated as "buying" from the internal supplier. A firm's make-or-buy decision is thus reformulated as a question of "from who, inside or outside of my firm, should I buy this" (Hoetker, 2005: p.76). His data include 116 introductions of innovative displays by 13 manufacturers. For each introduction of innovation, all potential suppliers in the database are identified, an observation is then generated for each potential supplier (including internal supplier). Specifically, the observation includes the supplier's technical capabilities—measured by the number of display-related US patents it applied for in the previous 5 years—and other variables of interest[33]. By doing so, the distribution of technical capabilities across the whole industry is captured. After estimating a series of logit models on the basis of 2716 valid observations, it is found that, *inter alia* , firms are more likely to choose a supplier if this supplier has greater technological capabilities[34], *ceteris paribus*.

Apart from the above highly supportive evidences, a few other studies produce mixed results that tend to provide more nuanced supports to the proposed links between a firm's existing knowledge-base (capability-base) and its boundary choice in face of make-or-buy.

For example, the finding of Mol (2005) is rather ambiguous. Using industry-level data from Dutch manufacturing sectors, he finds that—consistent with the prediction of capabilities view—R&D intensity, which could be understood as a proxy for a firm's technological base, has been negatively associated with the propensity to outsource in the early 1990s. However, there is a clear reversal over the 1990s in that the R&D intensity has ever since became a positive predictor for changes in

[33] Apart from a few control variables, Hoetker includes in his model various measures of (1) technical uncertainty and; (2) manufacturer-supplier relationship.

[34] A more explicit interpretation of their finding is that if a manufacturer possesses stronger technical capabilities than external supplier, it tends to make the product internal (i.e., to procure the product from internal supplier), if otherwise, an external supplier is preferred, and the manufacturer tends to choose the supplier with higher technical capabilities.

outsourcing levels, This suggests, firms in R&D intensive industries have increasingly started to rely on partnership relations with outside suppliers. The author hints the distinction made between of the breath and the depth of a firm's knowledge bases might be the clue to understand such reversal[35].

The findings of Mayer and Salomon (2006), by contrast, contribute to a more sophisticated understanding on the role of firm capabilities in shaping the boundary choice. On the basis of a random sample of 405 service contracts from a large IT firm, they examine independent and joint effects of technological capabilities on governance. To capture *separately* the firm's relative strengths and weaknesses in its productive capabilities, they employ a few dummy variables, each corresponding to a specific technological area. By estimating a series of probit models, Mayer and Salomon finds that weak technological capabilities increase the likelihood of subcontracting, but strong technological capabilities do not have a significant ***independent*** effect on governance choices. Moreover, by incorporating interaction terms in the models, it is also suggested—right or wrong as it might be[36]—that strong capabilities play a role in the presence of certain type of contractual hazard. To be more exact, it is shown that the interaction effect of strong capabilities is significant only for hold-up hazards but not for hazards of observability and appropriability. According to their interpretations, the results suggest, strong technological capabilities make it easier for a firm to identify, select, monitor, contract with, and manage contractors, helping a firm overcome certain types of contractual hazards. To put it even more explicitly, they interpret the results as implying that strong technological capabilities increase the threshold level of certain contractual hazard that a firm can effectively manage before turning to integration, and they call this "governance capabilities" (K. J. Mayer & Salomon, 2006: p. 955).

A more recent study by Qian et al. (2011) comes to similar conclusions, and their method is perhaps more rigorous[37] from a econometric point of view. Integrating

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[35] Some researchers (Brusoni, Prencipe and Pavitt, 2001) have noted that the breath and the depth are two distinct aspects of a firm's knowledge base. The further observes that firms generally know more than they make and that firms could "invest in broadening their knowledge bases while narrowing down their manufacturing bases" (Brusoni et al., 2001: p. 599). Following these ideas, the author suggest that if the deepening (narrowing down) of a firm's manufacturing base is moving at a faster pace than the broadening of its knowledge base, a firm will tend to be more dependent on outside supplier, even if its R&D investment (and accordingly, the R&D intensity) does not change significantly.

[36] As have been indicated above, in a logit/probit model, it is problematic to draw inference about the interaction effect from the coefficient of the interaction term. In this case, they use a probit model, and their conclusion about the interaction effects are exactly based on the estimated coefficient for various interaction terms.

[37] Compared with Mayer and Salomon (2006), the paper uses an improved method to examine the interaction effects.

insights from transaction-cost economics, capability-based view, and industry evolution literature, the study examine the firm's decisions regarding the organization of activities along a value chain. Using a near census sample of US bio-ethanol producers during the 1978-2009 period, they test their hypotheses. They find, *inter alia*, that activity-level pre-entry experience in a value-chain activity increases the likelihood to internalize that activity in the focal industry context. Moreover, by showing that pre-entry experience is associated with a better management of transactions hazard, thus moderating the effect of transaction hazard on the internalization choice, they find some support for the above-mentioned "governance capabilities" argument. Finally, their estimation results tend to support the conjecture that diversifying entrants possess "integrative capabilities" (Helfat & Campo-Rembado, 2010; Helfat & Raubitschek, 2000; Henderson, 1994)[38], making them more likely to internalize across value chain activities relative to entrepreneurial start-ups, and this effect persists throughout the industry life cycle.

5.2.2 Alliance

In the alliance literature, research on the outcomes of the firm's knowledge base tends to focus mainly on the relationship between participating firms' existing knowledge bases and the innovative performance of the alliance. Complementing this often explored relationship, there is a branch of literature that examines the impacts of the firm's existing knowledge/capabilities base on the formation and governance of the alliance (Wijk, Bosch, & Volberda, 2011).

In this branch of literature, it is generally held that the motivation for alliance participation is either to exploit the partner's complementary knowledge and other assets (T. Das & Teng, 2000; Grant & Baden-Fuller, 2004; Hennart & Reddy, 1997; Kay, 1997; Richardson, 1972; Teece, 1986; Tsang, 2000), or to learn from the partner to explore new knowledge combinations (Hamel, 1991; Inkpen, 1998; Inkpen & Tsang, 2007; Kale et al., 2000; Khanna et al., 1998; Larsson et al., 1998). "Absorptive capacity" (W. M. Cohen & Levinthal, 1989, 1990), in turn, is identified as central to the firm's ability to benefit from its alliance participation (Inkpen & Tsang, 2007; Lane & Lubatkin, 1998; Mowery et al., 1996b). Specifically, "absorptive capacity" is defined as "the firm's ability to identify, assimilate, and exploit knowledge from the environment" (W. M. Cohen & Levinthal, 1989: p. 569)—or alternatively, as "the ability of a firm to recognize the value of new,

[38] "Integrative capabilities" are defined as firm-level capabilities related to the "integration of activities via communication and coordination across the components of a system or across value chain activities at different stages of production" (Qian et al., 2011: p. 5) which cause firms to prefer internalization.

external information, assimilate it and apply it to commercial ends"(W. M. Cohen & Levinthal, 1990: p. 128)—and it is further argued that firms differ in their abilities to acquire and benefit from external knowledge sources because of the presence or absence of a relevant knowledge base. In such an organizational-learning perspective, the development of absorptive capacity is generally viewed as a cumulative, path-dependent process (Nelson & Winter, 1982; Richardson, 1972), and is usually the result of intensive internal R&D investment (W. M. Cohen & Levinthal, 1989; Rosenberg, 1990). Firms tend to accumulate deep knowledge within specific technological domains, which enables them not only to exploit their technological expertise, but also to recognize valuable new technological trajectories, to identify potential partners they can collaborate with, and to assimilate their partners' knowledge/capabilities to create novel knowledge (Wijk et al., 2011).

Two research themes can be further differentiated in this branch of literature, the first concerned with the impact of a firm's absolute knowledge base on alliance formation and governance, and the second with partner firms' knowledge base similarity. Below, we will review them *seriatim*.

A. Absolute Knowledge Base

As just mentioned, the first theme of the literature highlights the effects of a firm's ***absolute*** magnitude of knowledge base on its alliance behaviour. Following the logic of "absorptive capacity", it is loosely[39] argued that the more knowledgeable a firm is, the higher its absorptive capacity is, and the more likely it will enter into an alliance because its expectation of benefits from alliance participation is more certain (Wijk et al., 2011).

A.1 General Results

Empirical studies on this theme, however, report mixed results (see Table 5-2). Specifically, a majority of studies report a positive association between a firm's absolute magnitude of knowledge and its propensity for alliance participation (Arora & Gambardella, 1994; Bayona, Garcia-Marco, & Huerta, 2001; Colombo & Garrone, 1998; Colombo et al., 2006; Veugelers, 1997), while some report a negative association (Gary P. Pisano, 1990)[40], and still a few studies do not find any

[39] Arguments and hypotheses in this line of reasoning are less well developed.

[40] Admittedly, it is somewhat misleading to report the empirical results this way, since a result that finds a positive association between a firm's absolute magnitude of knowledge and its propensity for alliance participation could logically be compatible with a result that report a negative association. For example, in the context of choosing between in-house and alliance, a firm's absolute magnitude of knowledge is likely to be negatively associated with the choice of alliance, while this result is

significant relationships at all (Kleinknecht & Reijnen, 1992; Piga & Vivarelli, 2004). In short, although current insights lean towards a positive association (i.e., firms with a higher level of absolute knowledge-base have a higher propensity for alliance participation than those with a lower level of absolute knowledge-base), the empirical evidence is less conclusive.

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perfectly compatible with another result that reports a positive association between a firm's absolute magnitude of knowledge and the likelihood of choosing alliance in the context of a choice between alliance vs. market. In other words, the exact meaning of a positive/negative association between A and B depends on the context of the choice (as reflected in the dependent variable). We are aware of this potential logical pitfall.

Table 5- 2: Summary of the Empirical Studies on the Relationship between A Firm's Absolute Knowledge Base and its Propensity for Alliance Participation

	Study/Sample/Methodology	Relevant Dependent variable(s)	Relevant explanatory variables and their measures	Results
+	**Arora & Gambardella, 1994** **Sample**: The sample consists of all the large U.S. pharmaceutical and chemical corporations that were active in biotechnology in 1980s. (Number of Firms=26, Number of observations =178) **Methodology**: Poisson Regression; Negative Binomial Regression; Seemingly Unrelated Poisson Regressions (SUPR)	***AWF***: the number of collaborative agreements with other firms in biotechnology ***AWU***: the number of collaborative agreements with universities and other non-profit research centres in biotechnology	***Scientific Capabilities*** *SPS*: the average number of scientific papers published by the personnel of the firm to its total sales. ***Technological Capabilities*** a) *PAT*: the total number of U.S. biotechnology patents hold by the firm (intended to capture its technological skills). b) *RDS*: the ratio of R&D expenditures to sales (intended to capture the extent to which the firm is a 'research-oriented' firm).	PAT and RDS have a positive and significant impact on AWF. In other words, a firm with higher in-house technological capabilities has a higher propensity to come into alliance with other firms SPS has a negative and significant impact on AWF. This result is interpreted as meaning that firms with better scientific capabilities are better able to evaluate the true value of the project and will be more focussed on fewer but more valuable linkages. The effects of a firm's scientific and technological capabilities on its collaborative linkages with universities are less robust.
+	**Veugelers, 1997** **Sample:** The sample consists of about 290 R&D active Flemish companies, surveyed on their R&D expenditures for the period 1992-1993. **Methodology**: Simultaneous equations model that addresses the simultaneous relationship between the internal and external R&D. **Number of Observations**: 198 and 180 for the two equations respectively	***Cooperation dummy***: equal to 1 if company is engaged in R&D cooperation	***Internal R&D Expenditure:*** expenditures on internal R&D ***Reseach Orientation***: % of total R&D expenditures accruing to research	The more a firm spends on its internal R&D, the more likely it will engage in R&D cooperation. Companies with a more pronounced research orientation have a higher propensity for cooperation.

+	**Colombo & Garrone, 1998** **Sample**: The sample consists of 96 firms in the SDPT (semiconductor, data processing and telecommunications) industries observed during 7 years (1980-1986). Panel-type data are collected for the technological cooperative agreements they concluded and the underlying circumstances. **Methodology**: Simultaneous equations model **Number of Observations**: 665 and 570 for the two equations respectively	***TCA***: The yearly number of technical agreements concluded by a firm.	***R&D intensity of the firm***: the ratio of R&D expenses to firm sales for that year	The estimates of the TCA equation reveal that firm's internal R&D intensity has a positive and statistically significant impact on the number of collaborations in which they were involved, which provides clear support for the argument that firms' propensity towards technological collaboration increases with their autonomous R&D effort. Some initial evidence is also provided that the magnitude of the impact of R&D intensity on the propensity to collaborate depends on firm-, industry- and country-specific characteristics.
+	**Bayona, Garcia-Marco, & Huerta, 2001** **Sample:** The sample consists of 1653 R&D active Spanish manufacturing firms observed in 1996. Data on their R&D activities during 1994-1996 were collected by postal questionnaires. **Methodology:** Logistic Regression	***Cooperative R&D***: A dichotomous variable taking the value 1 if the firm has engaged in R&D cooperation.	***Systematic R&D****:* A dummy variable taking the value 1 when the firm's internal R&D activities are systematic and 0 if they are occasional. ***R&D Source:*** Importance of internal R&D as source of innovative ideas, measured by a 5-point Likert scale response to a survey question. ***Technological intensity***: Three dummy variables (high intensity, medium intensity and low intensity) are used to measure the technological intensity of the firm, each taking the value 1 if the firm belongs to that sector.	The coefficients for variables relating to the firm's own R&D capacity("systematic R&D" and "R&D source"), are estimated to be significant and have a positive sign, suggesting that firms which carry out internal R&D in a systematic manner, and firms which attach greater importance to their internal R&D have a higher propensity to cooperate. Both of the results are supportive of the theory of "absorption capacity". The coefficient for the dummy of "high intensity" is also estimated to be positive and significant, indicating that belonging to a high technological intensity sector increases the probability of establishing cooperative relationships[41].

[41] . The authors use the result as supportive evidence for the positive association between technological complexity and the propensity for alliance participation. As R&D intensity can also be used as an indication of a firm's technological capabilities, the same evidence, to a lesser extent, could be interpreted as being supportive of the theory of "absorption capacity". It is "to a lesser extent" because in this case, the R&D intensity is industry-specific rather than firm-specific.

+	**Colombo, Grilli, & Piva, 2006** **Sample**:The sample consists of 522 Italian young high-tech firms observed from 1994 to 2003. Longitudinal dataset regarding their alliance behaviour with the relevant information are constructed from various sources. **Methodology:** Cox proportional hazards model Cox proportional hazards competing risks model Panel data probit model	***Duration of time needed for firms to start their first alliance***(since foundation): measured in terms of years ***EURJVs*** (EU funded research joint ventures) ***participation***[42]: A dichotomous variable taking the value 1 for participation and 0 for non-participation.	***NPatents***: Number of patents granted to the firm.	The coefficient of NPatents is positive and significant (in the Cox proportional hazards model), suggesting that patent holding affects positively the likelihood to establish alliance. However, this propensity is found to rapidly decrease with firm size. With commercial alliances and purely technological alliance being further differentiated, it is found that the coefficient for NPatents (in the Cox proportional hazards competing risks models) is significant only for commercial alliance but not for technological alliance. Again, the positive effect of patent holding on the propensity to participate in commercial alliance decreases with firm size[43]. In the panel data probit model where EURJVs participation is the dependent variable, the coefficient for NPatents is positive but is not significant, suggesting that patent holding does not have a significant impact on a firm's propensity to participate in explorative technological alliance.

[42] EURJVs are cross-border alliances aimed at basic research or pre-competitive technological development. According to the authors, it could be considered as a good proxy of explorative technological alliances.

[43] The authors interpreted the result as indicating the signalling role of patents, i.e., patent holdings enable NTBFs (new technology-based firms) to signal their quality to would-be alliance partners through their previous technological accomplishments. Synergistic gains can be obtained when the focal NTBF and their partners with specialized commercial assets exchange access to their respective complementary assets, allowing a more successful commercial exploitation of the NTBF's innovation output. When the size of NTBFs increases, the inducement effect generated by lack of specialized commercial assets progressively disappears; therefore, the enabling effect of patents becomes less important.

-	**Pisano, 1990**[44] **Sample**: The sample consists of 30 top pharmaceutical companies which were active in pharmaceutical biotechnology R&D in the 1980s. Project-level Data on organizational choice of R&D activities and their circumstances are gathered from these companies. **Methodology**: Probit Regression **Numbers of observations**: 92	***Organizational Choice***: A dichotomous variable taking the value 1if the R&D project is organized completely in-house, or 0 if it is organized by collaboration with an external partner(s) via R&D contract[45] [46].	***BIOEXPERIENCE***: R&D experience in the relevant technology area, measured by the number of completed R&D projects by the firm in relevant biotechnology areas.	The coefficient of BIOEXPERIENCE is positive and significant, suggesting that a pharmaceutical firm will be more likely to undertake a biotechnology R&D project in-house when it has accumulated more in-house R&D experience in relevant technological areas. As the choice is made between in-house and collaboration, it also means prior R&D experience in the relevant technological areas leads to a lower propensity to establish collaboration in the same area.

[44] The result of the paper is often cited as being suggestive of a negative association between a firm's absolute magnitude of knowledge base and its propensity for alliance participation (e.g., Bayona et al., 2001; Zhang & Baden-Fuller, 2010; Zhang, Baden-Fuller, & Mangematin, 2007). Again, this is somewhat misleading, since in the paper, the organizational mode is the dependent variable with the choice made between in-house vs. alliance, and the sample is a group of top pharmaceutical companies; while in other papers we listed above, either the number of alliances, or alliance participation dummy is the dependent variable, and the samples are not always large established firms. To be more explicit, these "positive" and "negative" results might not be so contradictory as they were at first sight, and the argument that "***a large firm with more in-house R&D experience in a given field is more likely to organize its R&D in the field internally in the face of a choice between in-house vs. alliance***" might be perfectly compatible with another argument that "***a firm(not necessarily a large firm) with a higher level of knowledge has a higher propensity for alliance participation***".

[45] Licensing has been intentionally excluded from collaborative arrangements.

[46] As the study concerns explicitly only with the organization of R&D activities, the R&D activities are defined narrowly as "the activities needed to synthesize, formulate, and test a pharmaceutical product prior to human clinical trials" and do not include those "already progressed to the first phase of human clinical trials."
However, it seems to the author that the blanket term of "collaborative modes" (p. 164) actually includes both co-development and R&D outsourcing, which might in fact be very different in nature. As has been noted by Pisano himself, for most of the sample projects organized under "collaborative mode", the large firm is collaborating with a new biotechnology firm. In this case, "R&D is almost always the ***sole*** responsibility of the new biotechnology firm partner" and it corresponds very well to "external R&D". In other cases, the project involves two established firms, both of which contribute to the R&D effort and are literally ***collaborating*** with each other. In short, it is problematic to group ***R&D outsourcing contracts*** together with ***co-development contracts*** undifferentiatedly under the same category of "collaboration modes".

0	**Kleinknecht & Reijnen, 1992** **Sample:** A large sample of R&D active Dutch manufacturing and service firms (1929 firms) that is representative of the entire country in 1988. Data on the firms' R&D cooperation (excluding R&D outsourcing) and other relevant information (mainly firm-specific characteristics) are collected by survey. **Methodology**: Binomial logit and Multinomial logit **Number of observations**: 1929	***Participation in R&D Cooperation***: A few dichotomous variables that take the value of 1 if a firm cooperates with some other domestic (or foreign) firm (or R&D institution), 0 otherwise.	***R&D intensity:*** R&D man-years as a percentage of employees in a firm ***Various Sector dummies*** that take the value of 1 if the firm belongs to that sector ***R&D-dept:*** a dummy variable that takes the value 1 if the firm has a formal R&D department	Apart from cooperation with foreign R&D institutions, the R&D intensity of a firm has no significant impact on its propensity to cooperate. Sector dummies are significant only for some low- and medium-tech sectors (e.g. paper, printing and publishing; or public utility) but not for high tech sectors. The above results suggest that R&D cooperation does not typically occur between big, high tech firms which operate in global markets but occurs at least equally frequently between smaller firms in medium- and low-tech sectors. Except for cooperation with domestic firms, the coefficient of the dummy ***R&D-dept*** is significant for all the other types of cooperation, suggesting that the existence of internal R&D department is conducive to cooperation with the three other types of partners. The results tend to be supportive of the "absorptive capacity" argument.

+: positive association; -: negative association; 0: non-significant

More recent studies (Wijk et al., 2011; Zhang & Baden-Fuller, 2010; Zhang et al., 2007) indicate that the inconclusiveness of the findings can be attributed, in part, to the diversity of the measures that have been used to capture the firm's absolute magnitude of knowledge base and absorptive capacity, some of which are rather crude and each of which might emphasize a very distinct aspect of a firm's knowledge base. Following the clues in Cohen & Levinthal (1990)[47], it is further suggested that a firm's absolute magnitude of knowledge base can be observed from many different dimensions (Brusoni, Prencipe, & Pavitt, 2001; Matusik, 2002; Prencipe, 2000; Schmidt, 2010; Zahra & George, 2002), some of which could have quite different organizational consequences, including their impacts on the firm's propensity for alliance participation and the choice of governance structure.

A.2 Breadth and Depth of the Knowledge Base

A most widely accepted distinction made in this regard is that between the breadth (diversity) and depth (richness) of a firm's knowledge base (Bierly & Chakrabarti, 1996; W. M. Cohen & Levinthal, 1990; Granstrand et al., 1997; Prencipe, 2000; Turner et al., 2002; Wang & von Tunzelmann, 2000).

Specifically, the breadth of a firm's knowledge base is generally defined as the range of knowledge areas that a firm possesses (Brusoni et al., 2005; George et al., 2008; Wang & von Tunzelmann, 2000; Zhang et al., 2007; K. Z. Zhou & Li, 2011). A firm with a broad knowledge base is familiar with a wide range of technological territories on the knowledge landscape, and is thus capable of implementing wide scope search, often over unconventional search pathways, to explore new technological territories (Kauffman et al., 2000; Rosenkopf & Nerkar, 2001), to identify novel associations and linkages between distant knowledge sets (W. M. Cohen & Levinthal, 1990), and to discover non-obvious combinations of technological components that produce high-value solutions (Henderson & Cockburn, 1994; Katila & Ahuja, 2002). In a more dynamic view, a diverse knowledge base also enables the firm to monitor the evolution of technological trajectories and to recognize new opportunities that

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[47] As Cohen and Levinthal (1990: p. 131, emphasis added) state:
"Two related ideas are implicit in the notion that the ability to assimilate information is a function of the ***richness*** of the pre-existing knowledge structure: learning is cumulative, and learning performance is greatest when the object of learning is related to what is already known. As a result, learning is more difficult in novel domains, and, more generally, an individual's expertise—what he or she knows well—will change only incrementally. The above discussion also suggests that ***diversity*** of knowledge plays an important role. In a setting in which there is uncertainty about the knowledge domains from which potentially useful information may emerge, a diverse background provides a more robust basis for learning because it increases the prospect that incoming information will relate to what is already known. In addition to strengthening assimilative powers, knowledge diversity also facilitates the innovative process by enabling the individual to make novel associations and linkages."

deserve exploration (Dosi, 1982; George et al., 2008; Leiponen & Helfat, 2010). To be more exact, if a firm seeks to go beyond local search and innovate away from its current technological trajectory, it needs to span technological boundaries as well as organizational boundaries, and refer to external sources for knowledge and technologies beyond the technological domains of its current product offerings (Rosenkopf & Almeida, 2003; Rosenkopf & Nerkar, 2001). In this circumstance, a firm with a broader knowledge-base will have higher absorptive capacities (W. M. Cohen & Levinthal, 1989, 1990; Sampson, 2004b), which would ease the process of the identification, assimilation and exploitation of knowledge from external sources by relating new knowledge with its pre-existing knowledge-base (i.e., associative learning), Such advantage is particularly salient when the part of external knowledge a firm tries to access is tacit, and socially distributed (Zhang et al., 2007). Likewise, in an industry experiencing radical (architectural) technological innovation (Henderson & Clark, 1990; Langlois, 1988), knowledge and capabilities needed to realize such innovation are often dispersed across the whole industry, a diverse knowledge base would place a firm in a better position to build up system-level “architectural competence” or “integrative capability” by pulling together these dispersed knowledge/capabilities from various partner firms, and integrating them into a coherent whole (Henderson, 1994; Henderson & Cockburn, 1994; Leiponen & Helfat, 2010; Gary P. Pisano, 1994). Finally, knowledge diversity furnishes a firm with a stronger ability not only to discern potential partners, but also to evaluate the value of new technical projects offered by these prospective partners (Arora & Gambardella, 1994); relatedly, based on a better understanding of future technological trajectory, such a firm is better able to craft delicate contracts to regulate its relationship with its partners and to secure its benefits (Reuer & Tong, 2005). In other words, a firm with diverse knowledge base is more likely to have superior “governance capability” (Argyres & Mayer, 2007; K. J. Mayer & Argyres, 2004; K. J. Mayer & Salomon, 2006).

The breadth dimension captures the horizontal aspect (diversity) of a firm’s knowledge base, whereas the depth dimension reflects the vertical aspect (richness) of a firm’s knowledge stock within its core technological areas (Bierly & Chakrabarti, 1996). Specifically, the depth of a firm’ knowledge base is usually defined as a firm’s level of technological expertise in its core technological areas (George et al., 2008; Moorthy & Polley, 2010; Zhang & Baden-Fuller, 2010; K. Z. Zhou & Li, 2011). In the parlance of the theory of complexity and problem-solving (H. A. Simon, 1962), the depth of knowledge is concerned with the level of “analytical sophistication” of a specific subject, which “becomes complex because of the cognitive difficulty in pushing the particular matter to its logical extremes” (Wang &

von Tunzelmann, 2000: p. 806). As mentioned above, the development of a firm's knowledge base (and accordingly, its absorptive capacity) is a cumulative, path-dependent process, and is often the result of intensive R&D investment. To realize the gains from specialization (Demsetz, 1995b), especially cognitive specialization (Langlois, 2003a; Nooteboom, 2009), a firm tends to focus—at least as a first step—in a specific value chain and accumulate deep knowledge within relevant technological domain(s). The strategic importance of such deep knowledge has been highlighted by many scholars (March, 1991; Nelson, 1982; Nelson & Winter, 1982). According to them, a firm's R&D is fundamentally a problem-solving process of searching among alternative pathways characterized by trial-and-error experimentation (Nelson & Winter, 1982). A firm with deep knowledge in relevant fields will have a good understanding of the causal links within that niche—it knows what has worked (as well as not worked) in the past, and is more aware of the pitfalls over solution landscape. Accordingly, the firm is able to focus the search more finely, to decompose the problem into solvable sub-problems, to sequence the search in more efficient orders, and ultimately to improve its problem-solving efficiency for certain types of problems (Eisenhardt & Tabrizi, 1995; Nelson, 1982). Moreover, deep knowledge also allows a firm to exploit their technological expertise by making new combinations from old components, or by exploring new applications of the technology, as it understands the limitations of existing components from repeated use, and is able to identify and develop less apparent connections within the given sets of knowledge (George et al., 2008; Katila & Ahuja, 2002; March, 1991; Nerkar, 2003).

On the basis of the above ideas, some recent studies (Bonesso et al., 2011; Zhang & Baden-Fuller, 2010; Zhang et al., 2007) have empirically examined the relationships between the breath/depth of a firm's knowledge base, and its propensity to participate in R&D alliance as well as its choice of alliance governance.

On the one hand, as illustrated above, a firm with a broad technological knowledge base tends to enjoy more advantages when it uses research alliances. On the other hand, a broad knowledge base usually encompasses knowledge about how different components of systems interact, while such "architectural knowledge" is often embedded in the informal communication channels, information filters, and problem-solving strategies shared by R&D team members within an organization (Henderson & Clark, 1990; Henderson & Cockburn, 1994). In short, a broad knowledge base, by its nature, is systemic and socially complex, and is therefore difficult to replicate. Meanwhile, firms with a broad knowledge base can often learn at a faster rate than their partner in a learning race (Hamel, 1991), as their strong absorptive capacity facilitates the assimilation of new knowledge by relating it to their existing knowledge base. Summing up, firms with a broad knowledge base face a lower level of risk that their knowledge will be appropriated by their partners, while their benefits from alliance participation are more certain and more likely to outweigh the costs; consequently, they have more incentive to invest in exploring new technological opportunities with partners. Therefore, it is hypothesized that for incumbent firms, the breadth of the technological knowledge base is positively related to the likelihood of forming research alliances (Zhang & Baden-Fuller, 2010; Zhang et al., 2007).

By contrast, the effect of deep knowledge is seemingly working to the other direction. Specifically, for a firm with deep knowledge base in its core technological areas, sharing knowledge in alliance might result in unintended knowledge leakage to its alliance partners (Colombo, 2003; Oxley, 1997), which undermines the firm's competitive advantage and industry position. At the same time, a well-established firm endowed with deep knowledge may stand to learn much less from its partner than its partner can learn from it (Ahuja, 2000; Hamel et al., 1989; Khanna et al., 1998; Larsson et al., 1998). Given the relatively high costs of opportunism especially in the form of "appropriability hazard"(Oxley, 1997), and the relatively limited benefits of alliance participation, it is reasonable to argue that a firm with a deep technological knowledge base will be less inclined to use alliances (Ahuja, 2000), even though the depth of its knowledge endowments may make it more attractive to potential partners (Baum, Calabrese, & Silverman, 2000); at the same time, internal development or acquisition may often be a better option than alliance for such a firm (Rothaermel & Deeds, 2004). Based on the above argument, it is hypothesized that for incumbent companies, the depth of the technological knowledge base is negatively related to the likelihood of forming research alliances (Zhang & Baden-Fuller, 2010).

On the basis of two overlapping samples[48] of alliances formed between dozens of large focal firms active in the biotechnology sector, and their NBFs (new biotechnology firms) partners, Zhang and her co-authors test the above hypotheses (Zhang & Baden-Fuller, 2010; Zhang et al., 2007). Specifically, in their studies, the

[48] The data of the two studies are retrieved and compiled from the same database (BioCentry). In the first studies, the sample consists of 2647 strategic alliances (R&D alliances as well as other non R&D oriented "commercialization" alliances) formed by 43 major biopharmaceutical firms in the U.S. and Europe. In the second case, the sample consists of 1550 R&D alliances (i.e., to control for the focal firm's motivation for alliance participation, non R&D oriented "commercialization" alliances are intentionally excluded from the final pools used in data analysis) formed by 78 large focal pharmaceutical, chemical, and agro-food companies active in the biotechnology sector in U.S., Europe and Japan during the same period.

number of new alliances formed by each focal firm in a specific year is the dependent variable, while the breath and depth of a firm's knowledge base are measured by the number of bio-technological subfields in which the firm has been granted patents in the past five years, and a index of "concentration of knowledge base"[49], respectively. By estimating a series of negative binomial regression models, they find that, consistent with the predictions of the hypothesis, breadth and depth have opposite effects on the incumbent firms' propensity for alliance participation. A broader knowledge base adds to the probability of coming into alliances, whereas a deeper knowledge base works to contrary and the effect seems to be less significant than that of knowledge breadth.

Along a somewhat different route, Bonesso, Comacchio and Pizzi (2011) explore the role of knowledge breadth in the context of the choice between internal-versus-external[50] technology sourcing, and they come to a similar conclusion. Partially following the PSP (problem-solving perspective) reasoning, their study focuses not on the breadth of a firm's knowledge base but on the breadth of knowledge that is required to undertake a NPD (new product development) project. Using a small sample of project-level data collected from a group of leading Italian firms operating in the machine tool industry, they find that the higher the knowledge breath that is required to undertake a NPD project, the more likely the firm will refer to external technology sourcing, of which cooperative R&D arrangement is one of the option.

B. Knowledge-bases Similarity ("Knowledge-bases Overlap"/"Cognitive dissonance")

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[49] The index is computed in two steps. In the first step, the "Revealed Technological Advantage" (RTA) is computed as follows:

$$RTA_{it} = \left[\frac{P_{it}}{\sum_t P_{it}} \right] \Bigg/ \left[\frac{\sum_i P_{it}}{\sum_i \sum_t P_{it}} \right]$$

where P_{it} is the number of patents held by firm *i* in technology sub-field *t*. RTA_{it} is the ratio of the share of firm *i's* patents in technology sub-field *t*, to the share of all patents in that sub-field. It could be interpreted as an indicator of the firm's technological 'comparative advantage' in sub-field *t*.
In the second step, the coefficient of variation for the firm's RTA measures is computed, i.e.,

Concentration of knowledge base for firm i = $\frac{\sigma^i_{RTA}}{\mu^i_{RTA}}$

where σ^i_{RTA} is the standard deviation of RTA for firm *i*, and μ^i_{RTA} is mean value of the RTA for firm *i*.

[50] The blanket category of "external sourcing" encompasses a wide range of heterogeneous organization modes which includes: arm's-length arrangements (unilateral R&D contract, licensing agreement, etc.), various cooperative agreements, and outright acquisition of other firms. Such a practice is somewhat problematic, theoretically as well as econometrically.

Above we review the findings of empirical studies that examine the impact of a firm's ***absolute knowledge base*** on its propensity for participating in R&D alliances.

A second theme of the literature, by contrast, explores how partner firms' ***knowledge bases similarity*** ("knowledge-bases overlap"/"cognitive distance") might affect alliance formation and governance. Although we do not include such a measure in our research[51], with a view to present a more holistic picture of the whole literature, we still include a section summarizing the essence of the findings on this theme.

There are in fact two research questions in the literature on this theme: the first is concerned with how the similarity of the firms' knowledge bases influences their propensity to participate in technological alliances, and the second deals with how such similarity affects the choice of alliance governance.

Theoretical perspectives on the first question are relatively more uniform, and the underlying logic is straightforward. Following a knowledge-based and organizational learning view, it is argued that firms participate in R&D collaboration either to access the partner's complementary technological capabilities, or to learn from the partner to explore new knowledge. Given this, the success of a R&D alliance depends not only on the absolute absorptive capacities (W. M. Cohen & Levinthal, 1990) of the participating firms, but rather on their partner-specific (relative) absorptive capacities (Dyer & Singh, 1998; Lane & Lubatkin, 1998; Mowery et al., 1996b; Simonin, 1999a, 1999b) or so-called "cognitive distance" (Nooteboom, 1999, 2000). Specifically, partner-specific absorptive capacity refers to a firm's ability to absorb knowledge from a specific alliance partner which in turns depends on the extent to which partners have developed overlapping knowledge bases (Dyer & Singh, 1998; Lane & Lubatkin, 1998; Mowery et al., 1996b). To support a successful R&D alliance, some degree of technological overlap is necessary, since if two firms share little overlap in their knowledge base, they do not have the common ground to collaborate with and learn from each other (i.e., some knowledge in common is necessary if the partners are to benefit from non-common knowledge). However, at some point, the effect of such overlap on the likelihood of alliance formation exhibits negative returns. If two firms share a very high degree of overlap between their knowledge bases, neither of them has much to learn from the other, thus making it less attractive to participate in the alliance. In the extreme case, that two firms have identical knowledge bases, alliance is clearly an inferior option to internal

[51] We note that in the TCE literature, such a measure is often used as a proxy for the risk of "appropriability". We include appropriability as one of the explanatory variables, but we use a more direct (although subjective) measure to capture its effect.

development. In short, in the knowledge-based and organizational learning view, it is generally argued that there is an inverted-U shaped relationship between the overlap of the firms' technological bases, and the likelihood of their forming an alliance[52]—i.e., overlap of knowledge bases between firms is positively associated with the likelihood of alliance formation for low to moderate levels of overlap, but it becomes negatively associated with the likelihood of alliance formation at higher levels of overlap (Mowery et al., 1998).

On the empirical side, the findings of relevant studies tend to support the above inverted-U shaped relationship. In the first place, many studies (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008; Kim & Song, 2007; Nooteboom, Van Haverbeke, Duysters, Gilsing, & van den Oord, 2007; Schoenmakers & Duysters, 2006; Wuyts, Colombo, Dutta, & Nooteboom, 2005) find an inverted-U shaped relationship between the cognitive distance (or overlap) of the firms' knowledge bases and their innovative performance in R&D alliances, which is corroborative of the underlying rationale [53] for the alleged inverted-U relationship between the overlap of the firms' knowledge bases and their propensity for alliance participation. Moreover, limited evidences lend more direct support for the above argument. Using patent citation as a proxy for "technological overlap", Mowery el al. (1998) find an inverted-U shaped relationship between technological overlap and alliance formation in a sample of equity joint ventures established during 1985–1986. Similar findings have also been reported more recently by Oberoi (2011) in a sample of bio-technology R&D alliances formed between 1980 and 1994.

Apart from these generally supportive results, some studies report, at best, mixed results. The findings of Wuyts *et al*. (2005)[54] are of particular interests. In a sample

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[52] Nooteboom (1999) develops the same argument using a slightly different logic. He argues that a smaller cognitive distance (i.e. a greater overlap of technological knowledge bases) between partners eases communications and improves understandability, but it reduces novelty value in knowledge creation, while a large cognitive distance between partners (i.e. small overlap of technological knowledge bases), increases novelty value but makes communications difficult. If the effectiveness of learning by interaction is the mathematical product of novelty value and understandability, the result is an inverse U-shaped relation with cognitive distance, with the optimal level of cognitive distance (where the maximum effect of learning obtains) lying somewhere in-between the very low and very high levels of cognitive distance (Nooteboom, 1999). It should also been noted that the chain of logic applies not only to the relationship between cognitive distance and innovative performance in alliance, it could also be developed further to establish a link between cognitive distance and alliance formation.

[53] Given the inverted U-shaped relationship between cognitive distance and innovative performance in R&D alliances, if we further assume that likelihood of alliance formation increases with the expected payoff of technological innovation in alliance, it could be inferred that the likelihood of alliance formation has an inverse U-shaped relation with cognitive distance.

[54] The same paper also tests the inverted U-shaped relationship between ***cognitive distance*** and ***innovative performance*** in R&D alliances, but using another sample of pharmaceutical firms. The result has been reported above.

of ICT firms operating during 1981-1986, it is found that—contrary to the theoretical predictions—measures of ***technological cognitive distance*** have no significant effect on the likelihood of alliance formation, whereas indicators of ***strategic and organizational cognitive distance***[55] are found to have the expected inverted-U shaped relationship with propensity towards alliance. Overall, they conclude that on the basis of a broader interpretation of cognitive distance, the alleged inverted-U shaped effect could at least be partially supported[56]. The findings of Narula and Santangelo (2009) are of a similar nature. In their study, technological overlap (TECHOVER) is included as one of the control variables. On the basis of a sample of leading European ICT firms operating during 1978-1995, it is found that the TECHOVER is positively and significantly associated with the likelihood of alliance formation, while the coefficient for the square of technological overlap (TECHOVER2) is not significant, although it is negative. In other words, the results fail to confirm the hypothesized inverted-U shaped relationship[57].

Perspectives on the second question, by contrast, are less uniform. Following two different lines of reasoning, transaction cost economics and knowledge-based view make rather divergent predictions on how the overlap of partners' knowledge bases might influence alliance governance (Cantwell & Colombo, 2000; Colombo, 2003; McGill, 2007; Sampson, 2004b; van de Vrande et al., 2009).

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[55] The authors suggest that cognitive distance could be further differentiated along two distinct dimensions: technological and organizational. Technological cognitive distance refers to the differences in technological knowledge bases between firms, while organizational cognitive distance is the differences between firms in strategy and organization space. They further argue that organization and strategy of firms are the result of a historical, cumulative process that shapes the way firms interpret and react to the external word. Different strategic and organizational characteristics mirror the presence of different mental models, organizational routines, corporate culture, and management style. In particular, measures of firm size, diversification, and profit margins are considered to be indicative of the firms' cognitive differences in strategy and organization space. With these indicators taking similar values, firms are likely to adopt similar business models and have similar mental maps, organizational routines, corporate cultures, and management styles.

[56] The authors interpret the results in terms of the industrial context of their research. Specifically, they argue that in the mid-1980s, the ICT industry was probably in transit from the growth stage into the mature stage in which modular specialization took told, the dominant design emerged and innovations were mostly incremental and modular (as against radical and architectural). In this circumstance, organization is probably a more important issue than technology. Accordingly, the focuses of the firms were shifting from technology to organization for commercialization and efficient production, as well as to the design and implementation of new business models. In short, in the period under examination, alliances and inter-firm learning in ICT industries tends to be more oriented towards organization than technology, which eventually leads to a dominant design in organization.

[57] The authors note that their sample refers to a single industry within which the firms' knowledge overlaps are obvious higher than in inter-industry scenarios. They further argue that in intra-industry contexts the rationale for partnering is more likely to be to monitor competitors closely (in terms of technology as well as market) rather than to explore novel knowledge combinations. Therefore, even in conditions of "little" cognitive distance (i.e. greater overlap of technological specialization), firms may still opt for alliance formation.

The knowledge base argument is simple and direct (Colombo, 2003). If partner firms have developed highly overlapping technological bases, mutual learning will be easier *ceteris paribus*, as firms are better able to absorb each other's knowledge. Under such circumstances, the need for investing in more sophisticated coordination and communication mechanisms is considerably reduced, and so is the likelihood of resorting to more costly equity-based governance modes[58].

The prediction of TCE, however, is not immediately obvious (Colombo, 2003; Oxley, 2009). On the one hand, greater overlap in knowledge bases implies a higher level of mutual understanding, which makes easier not only the transfer of knowledge, but also the negotiation (*ex ante* stipulation of future contingencies) and implementation (*ex post* monitoring) of the contract, therefore reducing the haggling costs and leaving less room for opportunistic behaviour associated with 'hold-up' and adverse selection problems (Colombo, 2003; van de Vrande et al., 2009). On the other hand, greater overlap in knowledge bases gives rise to a higher level of partner-specific absorptive capacity and possibly a more direct competitive relationship, both of which add to the risks of unintended knowledge leakage to partners, thus leading to greater appropriability hazards (Colombo, 2003; Oxley & Sampson, 2004). As greater overlap in knowledge bases may lead to either an increase or a decrease of transactional difficulties; it is less clear whether it will favour the choice of equity or non-equity modes of governance.

However, as far as the appropriability hazards is of central concern (which is likely to be true for ***R&D*** alliances), it seems the relationship between knowledge-bases overlap and the probability of choosing the equity-based governance is likely to be inverted-U shaped (Oxley, 2009; Sampson, 2004b).

Specifically, it is argued that knowledge base diversity in an alliance influences both the incentives and the ability of a firm to misappropriate its partner's proprietary knowledge. When partner firms' knowledge bases are highly overlapping, it is easy to share knowledge, but there is little room for the firms to learn from each other and

[58] In the knowledge-based view, it is generally argued that the equity-based alliance (compared with contract-based alliance) is more efficient in mobilizing tacit and socially embedded knowledge to productive ends. In the first place, it is believed that with the aid of a whole package of coordination, communication and administrative mechanisms, the more hierarchical organization mode of the equity-based alliance is a superior means for transferring and/or sharing complex technologies/knowledge, as the hierarchical structure facilitates the cultivation of common codes of communication (Arrow, 1974), supports the development of common stocks of knowledge and a set of higher order organizing principles (Kogut & Zander, 1992). Moreover, the equity-based alliance permits knowledge substitution and greater flexibility (Conner & Prahalad, 1996), which not only economizes on limited cognition and the associated costs of learning, but also fosters better bilateral adaptation and contingent learning in an uncertain world.

the danger of misappropriation is reduced accordingly. In this case, the less protective contractual governance is more likely to be chosen. At intermediate levels of knowledge overlap, each partner tends to have its own unique knowledge. As a result, partner firms have greater incentive to misappropriate partners' knowledge since they have more to gain from such opportunistic behaviour, while their absorptive capacities are still sufficient to support such opportunistic misappropriation. In short, under this circumstance, there is greater need to neutralize the opportunistic incentives and to enhance hierarchical controls; consequently, it is more likely that the more protective equity-based governance mode will be chosen. At low levels of knowledge overlap, partner firms might potentially have a strong incentive to behave opportunistically; however, the threat of unintended knowledge leakage and misappropriation is mitigated by the lack of sufficient absorptive capacity, which in turns reduces the need for the safeguards of the more protective equity-based governance modes.

On the empirical side, Sampson (2004b) and McGill (2007) find evidence of an inverted-U shaped relationship between technological overlap and the choice of a equity-based governance structure in alliances. Sampson [59] interprets this as providing support for the TCE/appropriability logic, and undermining more competence-based explanations. Interestingly, Colombo (2003), in a similar study, finds a negative monotonic relationship between technological overlap and the likelihood of choosing a more hierarchical governance structure for alliance, and he interprets this as being supportive for the competence perspective. Overall, the question of how technological overlap might affect the governance choice in alliance remains open[60], and represents an interesting direction for continued future research (Oxley, 2009).

5.3 Empirical Findings Regarding the Governance Implications of Knowledge Tacitness and Social Distribution (Embeddedness)

[59] McGill (2007), by contrast, uses some sort of combination of arguments (from knowledge-based, TCE and real options views) to construct the inverted-U shaped relationship between equity-based governance and technological similarity. Accordingly, he interprets the result as indicating that alliance activities have "multi-theoretic foundations".

[60] Apart from the three papers mentioned above, van de Vrande *el al*. (2009) report rather mixed results which are hardly supportive of either view. (van de Vrande et al., 2009)

5.3.1 Theoretical Foundation: The work of Polanyi, Nelson and Winter

Despite the fact that Michael Polanyi's work on tacit knowledge (1958, 1966) is cited from time to time in the TCE literature[61], transaction costs theory does not generally consider knowledge tacitness as a factor that affects the firm boundary.

By contrast, it is widely acknowledged that Polanyi's ideas have had a profound influence on the knowledge-based view (Cowan, David, & Foray, 2000; N. J. Foss, 2003a; Grandori & Kogut, 2002; Miller, 2008). Indeed, to a large extent, the conceptions of tacit knowledge in the knowledge-based literature can be traced back to Nelson and Winter's (1982) work on evolutionary organization theory and Winter's (1987) chapter on knowledge taxonomy, both of which draw heavily on Polanyi's works.

Although it was not the intention of Nelson and Winter (1982) to develop a theory of the firm, in chapters 3 to 5 of this book, the two authors did, for the first time in the literature, highlight the central explanatory importance of tacit, experiential, contextual dependent and socially embedded knowledge and learning (which they label as "routines" and "capabilities") in the understanding of firm organization and behaviour (N. J. Foss, 2003a).

In the latter work, Winter (1987) presents the widely adopted knowledge taxonomy that distinguishes between the dimensions of tacitness vs. explicitness, teachability vs. non-teachability, observable vs. non-observable, complexity vs. non-complexity, and system-quality vs. stand-alone. This taxonomy has been the basis for much of the subsequent empirical work (N. J. Foss, 2012).

In short, the above two works essentially form the gateway through which the knowledge-based literature is linked to Michael Polanyi's work. It should nevertheless be noted that these two works are primarily concerned with the competitive and innovative implications of tacit and socially embedded knowledge, and it is less clear in these two works whether and how tacit and socially embedded knowledge might affect the firm's boundary choices.

5.3.2 Operationalization of the ideas: Kougt and Zander's work

On the basis of the above contributions (for a memoir, see Kogut & Zander, 2003), Kogut and Zander explore in a series of papers (Kogut, 1988a; Kogut & Zander, 1992, 1993, 1995, 1996; Zander & Kogut, 1995) the boundary implications of tacit

[61] For example, Polanyi (1958) is cited by Williamson (1985), and Hennart (1988).

and socially embedded knowledge. Partly inspired by their works, other contributors to the KBV further developed the theme (Hippel, 1994; Langlois, 1992; Langlois & Foss, 1999; Langlois & Robertson, 1995; Marengo, 1995; Spender, 1998; Tsoukas, 1996). As finely summarized by Langlois and Foss (1999), at the heart of these stories, is the argument that productive knowledge is often tacit and socially distributed—that is, knowledge required to perform a productive activity is often hard to articulate and not possessed by any single mind; instead, it is distributed among a group of interacting agents, emerging from the aggregation of the tacit knowledge elements of these interacting individuals. Moreover, such knowledge is often contextually sensitive in the sense that it can only be mobilized in the firm-specific context of carrying out a multi-person productive task. Given these characteristics of productive knowledge, when knowledge is to be transferred across firm interfaces, a firm may have difficulties understanding the knowledge and capabilities held by another firm, both firms separately and jointly may "know more than their contracts can tell" (Kogut and Zander 1992). In this setting, the costs of negotiating and making contracts with potential partners, of educating potential licensees and franchisees, of teaching suppliers what it is one needs from them, etc., become very real factors that shape the firm boundary (Langlois, 1992), and such costs are rather independent of considerations of opportunism (Kogut, 1988a; Kogut & Zander, 1992, 1993). Relative transformation costs of different firms seem to be the primary issue, not transaction costs (Kogut & Zander, 1995). Accordingly, it is argued that firms tend to internalize the utilization of tacit and socially distributed knowledge as internal replication economizes the costs associated with the transmission of such knowledge. In other words, in this view, what the firms "do better than markets is the sharing of and transfer of the knowledge of individuals and groups within an organization" (Kogut & Zander 1992: p. 383), and the firms can do so because they can supply a set of "higher-order organizing principles of how to coordinate groups and transfer knowledge"[62] (Kogut & Zander 1992: p. 388) that markets cannot offer. Ultimately, firms exist because "they provide a social community of voluntaristic action structured by organizing principles that are not reducible to individuals" (Kogut & Zander 1992: p. 384), because coordination, communication, and learning "are situated not only physically in locality, but also mentally in an identity" (Kogut & Zander 1996: 502).

[62] According to the authors, these "higher-order organizing principles" include, among others, "shared coding schemes", "values", and "a shared language". They act as "mechanisms by which to codify technologies into a language accessible to a wider circle of individuals" (Kogut & Zander 1992, p. 389); as a results, "varieties of functional expertise can be communicated and combined" (Kogut & Zander 1992, p. 390) within the social community of the firm.

Apart from the make-or-buy decision, in an even earlier paper (1988a), Kogut applies the same logic to the choice of alliance governances. He argues that equity-based alliances are more effective vehicles than contract-based alliances for the transfer of tacit and socially embedded knowledge between partners. According to Kogut, contract-based alliance forms are ruled out, "not because of market failure or high transaction costs as defined by Williamson and others but rather because the very knowledge being transferred is organizationally embedded". Pisano (1988) observes similarly that when a technology is highly tacit, licensing or other contractual means of knowledge transfer might not work. In this case, close cooperation such as joint venture may be the only vehicle by which particular R&D routines can be learned from the firm that has already mastered them. The line of argument is then further refined by Inkpen and his co-author (Inkpen, 1996; Inkpen & Crossan, 1995), who elaborate on the relative advantages of equity-based alliances in the sharing and transferring of tacit and socially embedded knowledge. Specifically, they note that equity-based collaboration forms (in particular, joints ventures) promote frequent and direct interactions among partners, which in turn tends to increase mutual understanding, enhance knowledge transparency and offer better opportunities for interactive learning. Each of the above aspects contributes to the facilitation of the sharing and transferring of tacit and socially embedded knowledge.

In addition to their contributions on the theoretical side, Kogut and Zander's pioneering work (Kogut & Zander, 1993; Zander & Kogut, 1995) on the empirical operationalization of knowledge tacitness and social (contextual) embeddedness has also been highly influential for subsequent research. Drawing on Roger's (1962) and Winter's (1987) taxonomies, the two authors operationalize the latent construct of knowledge tacitness in terms of the following two dimensions[63]: ***codifiability*** (which is designed to capture the extent to which the knowledge can be encoded or articulated in documents or other explicit forms) and ***teachability*** (which is designed to capture the ease by which know-how can be taught to new workers). In the later paper (Zander & Kogut, 1995) , the ***socially embedded*** aspect of knowledge is operationalized and measured by a multi-items scale (so-called ***system dependence***) designed to capture the degree to which relevant productive knowledge is distributed among many different people, thus increasing the difficulties of its transfer or imitation.

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[63] Complexity is initially (Kogut and Zander, 1993) included as a subordinate dimension of knowledge tacitness. In the later paper (Zander and Kogut, 1995), it is treated as a knowledge attribute related but independent of tacitness.

On the basis of the above operationalization and in a small sample of 35 major Swedish innovations, Zander and Kogut (1995) empirically establish that codifiability and teachability tend to speed significantly the transfer of innovative knowledge; however, system dependence and complexity do not seem to have a significant effect on transfer speed. As codifiability and teachability are negatively correlated to tacitness, the result confirms that tacitness implies higher levels of knowledge "stickiness" which impedes the knowledge reproduction process. More fundamentally, using the same sample, Kogut and Zander (1993) illustrate how tacitness affects organizational boundaries in the growth process. Specifically, it is shown that lower codifiability, lower teachability, and higher complexity are all good predictors of the choice of wholly-owned subsidiaries over other organizational forms in transferring innovative technological knowledge. Kogut and Zander (1993) claim that their results clearly support the view that "firms specialize in the transfer of relatively tacit and idiosyncratic knowledge" (Kogut & Zander, 1993: p. 640); ownership advantages in knowledge replication, not market imperfections, seem to explain organizational boundaries of the firm in this case. Overall, the results of these two empirical studies provide some initial empirical evidence regarding the thesis that tacit knowledge tends to be at the core of the idiosyncratic capabilities that shape both an organization's competitive advantage and its organizational boundary.

5.3.3 Empirical Findings

A. Transferability and the Competitive/Innovative Implications of Tacit and Socially Distributed Knowledge

Adopting similar measures to those developed by Kogut and Zander, many subsequent studies have explored further the multi-dimensional ramifications of tacit and socially embedded knowledge. Overall, the stream of literature is seemingly more concerned with the competitive/innovative rather than the boundary implications; and the discussions are placed more in the context of strategic alliance rather than in the case of make-or-buy.

In the first place, it has been repeatedly reported in this literature that knowledge tacitness is negatively associated with the performance of knowledge transfer[64] (Van

[64] The result of Minbaeva (2007) is an exception. In this study, Minbeava uses a composite index for knowledge characteristics (the average of four measures: non- codifiability, complexity, non-specificity and non-availability) as a regressor. It is hypothesized that the higher the degree of knowledge tacitness, complexity, nonspecificity and non-availability, the lower the degree of knowledge transfer to the subsidiary. In a sample of 92 Danish multinationals, it is found that, as predicted, the impact of knowledge characteristics on the degree of knowledge transfer has a negative sign, but the result is not statistically significant.

Wijk, Jansen, & Lyles, 2008), both within (Szulanski, 1996, 2000; Szulanski, Cappetta, & Jensen, 2004)[65] and across the firm boundary (C.-J. Chen, 2004; Inkpen & Pien, 2006; Nielsen & Nielsen, 2009; Simonin, 1999a, 1999b, 2004) [66].

Moreover, empirical evidence also lends support to the central tenet of the knowledge-based view that tacit knowledge is at the core of sustainable competitive advantage (Barney, 1991; Lippman & Rumelt, 1982; Nelson & Winter, 1982; Reed & Defillippi, 1990). Specifically, it has been found that the stock of collective tacit knowledge in teams (i.e., non-individual, socially embedded tacit knowledge) is positively associated with team performance (Berman, Down, & Hill, 2002). In the context of alliance, it is similarly found that the acquisition of tacit knowledge (from alliance partners) has a greater positive impact on the firm's competitive (Lyles & Salk, 1996) and innovative (Cavusgil, Calantone, & Zhao, 2003; Nielsen & Nielsen, 2009) performance than less tacit knowledge. More fundamentally, it has been shown that the degree of tacitness of a firm's technological knowledge is positively related to the persistence of its major performance advantages [67] (McEvily & Chakravarthy, 2002). Overall, the evidence tends to suggest that tacitness of knowledge increases its 'stickiness', which adds to the barriers of imitation and ultimately helps the firm defend its competitive advantages.

Compared with tacit knowledge, the transferability and the competitive implications of socially embedded knowledge are relatively less examined empirically[68], but the

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[65] In these few studies, causal ambiguity, a composite measure of knowledge characteristics that includes tacitness is used as the regressor. See also footnote 6.

[66] Szulanski, and Simonin follow a slightly different route in addressing the impacts of knowledge tacitness (and social embeddedness) on knowledge transferability. Specifically, in their studies, it is argued that tacitness does not have a direct influence on knowledge transfer; rather, its effect is mediated by knowledge ambiguity. On the theoretical side, the argument is first proposed by Reed and DeFillippi (1990), who identify tacitness as one of the major sources of knowledge ambiguity that raise barriers to imitation (the other two sources being complexity and specificity).

[67] The authors distinguish between major and minor performance improvement of the firm's product in accordance with the degree of its technological advance. Specifically, a major performance improvement is defined as one that (1) offers customers substantially higher performance than existing versions of a product, or (2) embodies a new combination of performance characteristics that existing products do not offer.

It is also found that there is a significant ***negative*** association between knowledge tacitness and the duration of ***minor*** performance advantage. This suggests, the ability to make minor improvements tends to draw on articulable and well understood relationships between product components and performance outcomes.

[68] A proportion of the literature is not particularly concerned about the difference between knowledge tacitness and social embeddedness. For example, Berman et al. (2002: p. 16) submit that "knowledge that is both dispersed and embedded within a network of social relations ***by its very nature tends to be tacit***". In that study, they use shared team experience as a proxy for tacit knowledge and explore the performance implications of tacit knowledge. By doing so, they seem to have merged the two variables into one. Some recent literature (Inkpen & Dinur, 1998; Lam, 2000) explicitly argues that tacitness and social emeddedness are two related but different aspects of knowledge characteristics.

limited number of studies come to highly similar findings to those for knowledge tacitness (Collinson, 1999; Lam, 1997; Nielsen, 2005).

B. Governance Implications of Tacit and Socially Distributed Knowledge

B.1 Implications for Relational Governance

As mentioned above, empirical research on tacit and socially distributed knowledge tends to focus on its competitive/innovative rather than governance implications. Within the stream of empirical literature that explores its governance implications, a majority of studies investigate the relationship between knowledge tacitness and relational governance, whereas its ramifications for formal governance are relatively less explored.

Given the focus of current study, it is sufficient simply to summarize the major findings of the relational governance literature without going into details. In this literature, it has been repeatedly reported that relational governance mechanisms, which function on the basis of trust, mutuality and other norms for cooperative relationship, tend to have a stronger positive influence on the transfer of tacit knowledge than explicit knowledge[69] (Becerra, Lunnan, & Huemer, 2008; Dhanaraj, Lyles, Steensma, & Tihanyi, 2004; Evangelista & Hau, 2009; D. Z. Levin & Cross, 2004; Nielsen & Nielsen, 2009). According to the sociology-oriented relational governance theory, this is the case because trust and other socially derived norms and social ties that emerge from prior exchange can serve as coordination and incentive/control mechanisms that ensure repeated intense interaction, encourage open communication, enhance information transparency and reduce uncertainty (Bradach & Eccles, 1989; Dyer & Singh, 1998; Macaulay, 1963), all of which facilitate the transfer of tacit knowledge (Nielsen & Nielsen, 2009; Uzzi, 1996, 1997). By contrast, trust is not really as important for the exchange of explicit knowledge,

[69] However, the study by Szulanski et al. (2004) comes to a different conclusion. Following Mayer et al. (1995), they differentiate between ability-, benevolence- and integrity-based trust. They then identify ability-based trust as of greatest consequence in intra-firm knowledge transfer. In a sample of intra-firm transfer of best practices, they find that as causal ambiguity of knowledge (of which tacitness is a major source) increases, the impact of the perceived ability-based trustworthiness of the knowledge source on the performance of the intra-firm knowledge transfer (using transfer accuracy as a proxy) tends to weaken progressively and then becomes ***negative***. In other words, when causal ambiguity is high, trustworthiness may prove counterproductive. They explain that this is because at high levels of causal ambiguity, an increase of trustworthiness of the knowledge source's ability may result in less vigilance or attention on the part of the knowledge recipient, while such vigilance or attention is essential for the receipt of knowledge.
It might also be worth noting that Levin and Cross's study (2004) uses a similar framework that differentiates between competence-based and benevolence-based trust, but their result suggests to the contrary—i.e., competence-based trust is more important to the receipt of useful knowledge when that knowledge is tacit as opposed to explicit.

which can be codified and therefore be transferred independently of close relationships, although the transfer of explicit knowledge may be enhanced by the presence of trust as well (Becerra et al., 2008; Dhanaraj et al., 2004).

B.2 Implications for Formal Governance Mechanisms

Above, we present the main empirical findings regarding the relative efficiency of relational governance in facilitating the transfer of tacit vs. explicit knowledge. For the purpose of this study, we are more interested in the implications of tacit and social embedded knowledge for the choice of formal governance mechanisms—i.e., how it affects the make-or-buy decision or the choice of various alliance forms. Unfortunately, empirical studies in this regard are seriously underdeveloped, either compared with the relative abundance of empirical literature that investigates the role of relational governance, or compared with the profusion of conceptual work on relevant topics (to mention a few, Argote & Ingram, 2000; Contractor & Ra, 2002; Heiman & Nickerson, 2002; Inkpen & Dinur, 1998; Lam, 2000; Tsang, 2000). That being said, limited progress has been made that helps to shed more light on the role of tacit and socially embedded knowledge in shaping the choice of formal governance mechanisms.

In the first instance, a limited number of empirical studies (C.-J. Chen, 2004; Heiman & Nickerson, 2004; Mowery et al., 1996b; Shenkar & Li, 1999) have explored the implications of knowledge tacitness for the choice of alliance governance, and the results of these studies tend[70] to confirm Kogut's (1988a) "received wisdom" that equity-based alliances are more effective vehicles than contract-based alliances for the transfer of tacit knowledge between partners. Among these few studies, Heiman and Nickerson's (2002, 2004) view is probably the most nuanced as it refines and extends Kogut's thesis by incorporating the logic of the problem solving perspective and transaction cost economics.

Specifically, they argue (Heiman & Nickerson, 2002, 2004) that inter-firm collaboration can be understood as a problem solving process via the combination of distinct knowledge sets that are often tacit and dispersed. Given the cognitive limitations of human beings, knowledge attributes such as its tacitness and the extent to which knowledge is dispersed across many individuals (knowledge dispersion) can interact with the problem complexity to pose significant challenges for knowledge sharing/transferring in the process of searching for a valuable solution.

[70] The study by Clarke et al. (2008), published in a less well-known journal, is an exception. In the context of international market entry, the results of the study fail to establish a significant positive association between knowledge tacitness and the likelihood of choosing equity-based entry mode.

To cope with the challenge of increasing tacitness, certain knowledge management practices (KMP) such as high-bandwidth communication channels and common communication codes can be adopted to facilitate the sharing/transferring of tacit knowledge. However, given the behavioural assumption of opportunism, the adoption of these measures gives rise to higher knowledge appropriation hazards via increased knowledge transparency. Efficient inter-firm collaboration governance, therefore, should address the problem of knowledge transfer and knowledge expropriation jointly. Heiman and Nickerson suggest, of two categories of alliance governance (i.e., equity-based and contract-based), equity-based alliance is a better choice for addressing both problems. On the one hand, with the aid of a whole package of coordination, communication and administrative apparatuses, the equity-based alliance is seemingly a superior vehicle for transferring/sharing complex knowledge, as the hierarchical structure is better able to accommodate high bandwidth communication, to cultivate the development of common communication codes and to facilitate the formation of higher order organizing principles. On the other hand, the equity-based governance mode could, at the same time, provide better safeguards against the possible misappropriation of knowledge resulting from increased knowledge transparency, as shared ownership tends to alleviate opportunistic incentives, increase monitoring and enhance managerial controls.

In a sample of publicly-announced alliances formed between 1977 and 1989, they (Heiman & Nickerson, 2004) establish empirically most of the critical linkages in the above chain of relationships; most importantly, they find that the more tacit the relevant knowledge is, the more likely that equity-based alliance will be chosen to govern the technological collaboration.

Apart from knowledge tacitness, Heiman and Nickerson (2004) also examine the effect of knowledge dispersion—which reflects "how 'spread-out' knowledge is among different people in a collaboration" (p. 408). Their results provide some preliminary support to the argument that knowledge dispersion is positively associated with both the adoption of more costly knowledge management practices and the choice of equity-based governance form. Moreover, it is also suggested that the above dispersion-related effects are exacerbated in the presence of complexity and tacitness. Finally, we note that Heiman and Nickerson's paper (2004) is one of the very few empirical pieces that explicitly investigate the boundary implications of socially embedded knowledge. Given this, it seems fair to comment that compared with the already underexplored dimension of knowledge tacitness, the boundary implications of social embeddedness are even more unexplored.

5.3.4 The Codification Debate

Before proceeding to the next section, we also discuss briefly some of the relevant issues that have been raised in the recent "codification debate" (Ancori, Bureth, & Cohendet, 2000; Balconi, 2002; Balconi, Pozzali, & Viale, 2007; Cowan et al., 2000; Gourlay, 2006b; Johnson, Lorenz, & Lundvall, 2002; Nightingale, 2003; Nonaka & von Krogh, 2009; Ribeiro & Collins, 2007). The unresolved debate is largely on the conceptual and theoretical side. It is concerned mainly with the exact meaning of "tacit knowledge", which is said to have been clouded by "a considerable amount of semantic and taxonomic confusion" (Cowan et al., 2000: p. 213); but the discussions also extend to its empirical relevance and precision. Given the nature of this section, we do not intend to review in detail each point of contention that defines this debate[71], suffice it to say that the following points relevant to the current discussion seem to emerge from the debate.

In the first place, it has been noted (Gourlay, 2006b) that tacit knowledge has been operationalized on different levels by different authors. Many treat it as personal, private knowledge, and operationalize tacit knowledge only at the individual level (Ambrosini & Bowman, 2001; Boiral, 2002; Johannessen, Olaisen, & Olsen, 2001; McEvily & Chakravarthy, 2002). Others hold that tacit knowledge manifests itself mainly in a supra-individual if not collective form; and they tend to focus on collective or organizational tacit knowledge and link it directly with certain aggregate-level constructs (e.g., organizational capabilities, routines, and procedures) (Collins, 2001; Collis, 1994; Nelson & Winter, 1982). Still others recognize explicitly that tacit knowledge exists both on individual and collective/organizational levels, each with its own boundary implications (Inkpen & Dinur, 1998; Lam, 2000). Apparently, the fact that tacit knowledge has been operationalized on different levels has resulted in considerable lexical ambiguity and confusion. In particular, we note that *tacit knowledge* in its collective form is highly overlapping with what we refer to as *socially dispersed(embedded) knowledge.* As we have shown above, the propensity to merge *knowledge tacitness* and *social embeddedness* into a single construct (or the failure to distinguish the two) has led to some confusion in the empirical literature. Undoubtedly, there is a need, both analytically and empirically, to better distinguish the effects of these two constructs. However, it is not

[71] Topics of the debate include, among others, the distinction between knowledge and information; the nature of the dichotomy between tacit and codified knowledge (e.g., to what extent tacit knowledge could be converted into codified knowledge, the need to distinguish inherently tacit knowledge from codifiable knowledge etc.); the impact of information technology on the codifiability of knowledge; better operationalization and empirical measurement of tacit knowledge.

particularly clear what is the exact relationship between the two—say, is social embeddedness a subset of knowledge tacitness?

Relatedly, it has become increasingly clear that there are indeed different types of tacit knowledge, with different causes and consequences (Balconi, 2002; Collins, 2007, 2012; Gourlay, 2006a; Pozzali, 2007; Pozzali & Viale, 2007; Ribeiro & Collins, 2007). One illuminating distinction that has been made is that between "***somatic-limit tacit knowledge***" and "***collective tacit knowledge***"(Collins, 2007)[72]. According to Collins, ***somatic-limit tacit knowledge*** has to do with the limitations of the human body and brain, and it poses little challenge for encoding knowledge into machines. This type of tacit knowledge is exactly what Polanyi (1958) talks about in his famous bike riding example. As explained by Polanyi, the knowledge about bike-riding is tacit not because it cannot be formalized into explicit rules, but because these rules cannot be used by humans to help them ride. Collins asserts that tacit knowledge of this kind could, in principle, if not in practice, be converted into explicit rules and/or executed by robotic mechanisms; humans cannot make use of these rules to carry out corresponding activities simply because they are bound by their somatic limits[73]. Collective tacit knowledge, by contrast, is more ontological than biological. It is something that human individuals, and only human individuals, can acquire, because their body and brain's unique capacity give them "*special and continual access to the location of knowledge—which is the social collectivity*"(Collins, 2007: p. 261) [74]; known and foreseeable machines do not have

[72] In his latest book (Collins, 2012), a third type of tacit knowledge—relational tacit knowledge—is further identified. According to Collins, relational tacit knowledge has to do with social relations, it is the kind of tacit knowledge that you can explain, but don't, for one reason or another. Specifically, it includes secrets, the things you don't know that you know, and the things you can't explain because you don't know what the other party needs to know. Collins emphasizes that tacit knowledge of this type is "relational" because whether it is tacit or made explicit depends on the relation between the parties. The other two types of tacit knowledge, by contrast, do not become explicit when social arrangements change.
Collins also assert that these three type of tacit knowledge, which have to do, respectively, with the contingencies of social life (relational tacit knowledge), the nature of the human body and brain (somatic tacit knowledge), and the nature of human society (collective tacit knowledge), are the weak, medium, and strong form of tacit knowledge.
As the further differentiation of this weak form of tacit knowledge does not affect our basic conclusion, to keep our discussion focused, we still use the old classification.

73 Collins demonstrates this point by means of a thought experiment. Specifically, suppose our brains and nerve impulses were speeded up a millionfold; at the same time, further suppose that everything slowed down enormously, and the loss of balance happened much less quickly (say, bicycle-riding on the moon). In this case, the bike might fall over so slowly that there would be enough time to read a set of balancing instructions and follow them in the new, much slower, real time. Bike-riding would then become more like assembling flat-pack furniture: you hold the instructions in one hand and obey them without any significant time constraints. Overall, the upshot is, once the physics of bike-riding are not so forbidding, the limited human organism could then use an articulated version of the normally tacit knowledge to ride a bike.

[74] Collins also relates this type of tacit knowledge to Wittgenstein's (1953) "forms of life" argument—i.e., rules of action do not contain the rules for their application. For example, to apply a rule that "do not walk too close to others in the street," one must know what "too close" means and how it varies

this capacity. The famous bread-making machine example can be used to illustrate the nature of the so-called "*collective tacit knowledge*"[75].

Back in the 1990s, Nonaka and Takeuchi (1995) claimed that a master baker's tacit knowledge could be and has been made explicit and incorporated into a home bread-making machine and its manual—which is generally known as the 'knowledge capture' thesis. To test the claim, Ribeiro and Collins (2007) compared bread made with and without a bread maker, and they carried out an analysis of the bread-making actions before and after mechanization. It is shown that the machine only mimics the mechanical counterpart of just a few of certain special kinds of human bread-making actions. The remaining success of the bread-making machine and its manual is due to what other human actors bring to the mechanical bread-making scene, which corresponds roughly to the so-called collective tacit knowledge. Basically, the success of the bread-making machine is not a matter of the explication or incorporation of tacit knowledge, as it is alleged by Nonaka and Takeuchi (1995), but of fitting a social prosthesis into a rearranged world.

Admittedly, the above discussion, especially the part involving "collective tacit knowledge", has proceeded on a highly philosophical level and the exact nature of the so-called "collective tacit knowledge" is rather ambiguous. Some others authors (Balconi, 2002; Johnson et al., 2002; Pozzali, 2007; Pozzali & Viale, 2007), by contrast, have noted roughly the same phenomenon and discussed its implications in a more practical manner, of which Balconi's (2002) work is particularly worth noting. Balconi (2002) observed that, in the past decades, the widespread adoption of computer-based automation and the corresponding wave of knowledge codification have literally reshaped the manufacturing world. In this process, traditional tacit skills of craft workers, which relied mainly on "the perceptions of sensory organs or manual ability"(Balconi, 2002: p. 361), has become largely obsolete as this type of tacit knowledge has increasingly been codified, and then executed by automatic

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from circumstance to circumstance, and one must know another set of rules to know how to recognize what kind of circumstance it is, and so forth.

[75] Another example that Collins uses to illustrate the nature of "***collective tacit knowledge***" is that of bicycling in traffic (Collins, 2007).

Collins points out that the bike-riding example as described by Polanyi should really be called bike-balancing. In addition to balancing, proper bicycle-riding has to deal with additional problems of negotiating traffic. Collins asserts that negotiating traffic is a problem that is different in kind to balancing a bike, because it includes understanding social conventions of traffic management and personal interaction. For example, it involves knowing how to make eye contact with drivers at busy junctions in just the way necessary to assure a safe passage and not to invite an unwanted response. And it also involves understanding how differently these conventions will be followed in different locations. For example, bike riding in Amsterdam is a different matter than bike riding in London, or Rome, or New York, or Delhi, or Beijing—where bicycles are ridden at night without lights, in ways that would be considered absolutely suicidal in the West.

devices. This, however, does not mean that tacit knowledge has become less relevant. Another type of tacit knowledge that complements codified and automated manufacturing processes has been even more important. Specifically, this type of tacit knowledge concerns problem solving heuristics, interpretation of data, intuitive pattern matching judgement, and so on. It serves to decode and assign meaning to information-bearing messages, to choose actions by matching rules to situations, and to create novelties. According to Balconi, tacit knowledge of this type, by its nature, is inherently tacit and uncodifiable.

If we compare the analyses by the two authors, it seems clear that what Collins (2007) refers to as "somatic-limit tacit knowledge" is basically the same kind of tacit knowledge of craftsmanship described by Balconi (2002)[76]. According to both authors, this type of tacit knowledge poses no challenge to codification. Balconi observed further that the diffusion of computer-based automation, the wave of codification of tacit knowledge of this type, together with the accelerated pace of innovation have had a significant impact on the boundary choices of the firms in some industries, leading them to vertical disintegration.

We are not particularly sure, however, about the exact relationship between the so-called "collective tacit knowledge"—as defined by Collins (2007)—and the second type of tacit knowledge described by Balconi (2002)[77,78]. That being said, it is obvious, from the discussions of the two authors, that at least some type of tacit knowledge cannot not be codified and executed by automatic device. This implies, the "knowledge capture" thesis (Nonaka & Takeuchi, 1995)[79], which hold that all knowledge could potentially be "converted" into explicit knowledge and "embodied" into a machine, is highly problematic.

Summing up, the recent "codification debate" reminds us that, to better understand the organizational implications of knowledge tacitness, there is a need, analytically as well as empirically, to further distinguish different types of tacit knowledge, and

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[76] In a later article, Balconi et al. (2007) label this type of tacit knowledge as "tacit knowledge in the form of physical, kinaesthetic or skill-like abilities" (Balconi et al. 2007, p: 840).

[77] The second type of tacit knowledge is later labelled as "tacit knowledge of a cognitive type" (Balconi et al., p: 840) or "implicitly held cognitive rules" (Pozzali & Viale, 2007: p. 218).

[78] On the face of the definition, it seems that "tacit knowledge of a cognitive type" could be collective as well as personal. The example of the former category would be Apple's abilities to design next-generation mobile handsets, while the example for the latter category would be Terence Tao's skill to solve a math problem.

[79] In this viewpoint, tacit knowledge is noting but "hidden" (Nonaka & Takeuchi, 1995: p. 71) or "knowledge-not-yet-articulated" (Tsoukas 2005: p. 154), waiting to be uncovered and explicated; it is also suggested that whether any given knowledge remains tacit and unexpressed is determined by the different cost/benefit structures associated with the codification operation.

to operationalize the construct in a more precise manner.

5.4 Conclusions

Above, we offer a detailed review of the empirical evidence relevant to our study. We now summarize the key findings of our review.

As far as the make-or-buy choice is concerned, the limited existing empirical evidence relevant to the first category of variables (mostly derived from studies that were expressly designed to examine the problem solving perspective) are rather supportive of the PSP predictions—i.e., the more complex, and the more ill-structured a technological problem is, the more likely that the problem solving will be organized internally. When the choice is between various forms of alliance, it is found that the more ill-structured and the more complex an inter-firm collaboration is, the more likely that an equity-based alliance will be chosen to govern this collaboration. Moreover, it has also been found that, in the face of complexity, the adoption of equity-based governance is mainly motivated by concerns over coordination issues rather than incentives alignment. To put it somewhat differently, the empirical evidence indicates that the major challenge of greater complexity for the governance of inter-firm collaboration is mainly on the coordination side, not incentives alignment. Obviously, this is more supportive of the predictions of the problem-solving perspective rather than transaction cost economics.

Empirical evidence regarding the boundary implications of complexity can also be found in the empirical TCE literature. Generally speaking, the relevant empirical evidence in this literature leans toward a positive association between complexity and vertical integration. However, in this literature, there is considerable ambiguity concerning the meaning of “complexity”, and there is also a considerable diversity in its operational measures. Hence, in most cases, the same result is liable to multiple interpretations. Given this, relevant empirical evidence in the TCE literature is far from being conclusive.

As noted above, in the problem solving literature, the organizational implications of a firm’s existing knowledge base are largely ignored. By contrast, in the knowledge-based view literature, the theme has been explored to some extent, although not necessarily in the context of a firm’s problem solving (technological development) activities. Generally speaking, when the choice is between “make” or “buy”, the empirical evidence in the knowledge-based view literature tends to support a positive association between a firm’s existing knowledge-base and the choice of internal organization (i.e., the higher the firm's existing knowledge base is, the more likely that productive activities will be organized in-house).

In the context of alliances, existing empirical studies tend to focus on the relationship between a firm's existing knowledge base and its propensity for alliance participation. Although current theoretical insights lean towards a positive association (i.e., firms with a higher level of absolute knowledge-base have a higher propensity for alliance participation than those with a lower level of absolute knowledge-base), the empirical evidence is less than conclusive.

More recent studies indicate that the inconclusiveness of the findings can be attributed, in part, to the diversity of the measures that have been used to capture the firm's absolute magnitude of knowledge base. In this context, the breadth and the depth of a firm's knowledge base are further differentiated, and it is argued that a broader knowledge base adds to the possibility of coming into alliances, whereas a deeper knowledge base works to the contrary. Both of the hypotheses are then tested empirically, and the results are broadly corroborative.

Empirical evidence relevant to the third category of variables is probably most underdeveloped. Overall, the stream of empirical literature is seemingly more concerned with the competitive/innovative implications rather than the boundary implications of tacit and socially distributed knowledge. Within the stream of empirical literature that explores the governance implications of tacit and socially distributed knowledge, a majority of studies investigate the relationship between knowledge tacitness and relational governance, whereas its ramifications for formal governance are relatively less explored. That being said, a limited number of empirical studies have explored the implications of knowledge tacitness for the choice of alliance governance, and the results of these studies tend to confirm Kogut's (1988a) "received wisdom" that equity-based alliances are more effective vehicles than contract-based alliances for the transfer of tacit knowledge between partners. An even smaller number of studies investigate the boundary implications of socially embedded knowledge, and the very limited empirical evidence provides some preliminary support for the argument that knowledge dispersion is positively associated with both the adoption of certain more costly knowledge management practices (e.g., high-bandwidth communication channels) and the choice of equity-based governance form.

Chapter 6: Econometric Analysis

Using data collected from the Chinese consumer electronics industry, we will empirically examine in this chapter the underlying determinants of the firms' organizational choice for their R&D activities, which, in the first place, is deemed as a problem solving process given their existing knowledge base. Special attention is therefore devoted to those variables associated with the problem-solving approach in the KBV.

This chapter will proceed in the following manner. We start in section 1 by outlining the method and process of our data collection; on the basis of the best available background information, the characteristics and representativeness of our data set are also described. In section 2, we explain how the dependent and independent (explanatory) variables in our analyses are defined and measured. In section 3, the organizational choices are treated as a series of binary choices and the probit regression technique is used to identify the determinants of these choices. Specifically, the section begins with a brief discussion on some of the technical details of the binary probit model. Using probit regression technique, the estimation results of the whole series of binary probit models are then presented and the underlying determinants in each circumstance are separately identified. In section 4, we introduce at some length the technical details of the multinomial logit model. On the basis of these technical discussions and using the first-stage results as a benchmark, we present the results of the multinomial logit estimation. Much of the efforts are devoted to the identification of the determinants of the organizational choices within this more integrated framework.

6.1 Data Collection

6.1.1 Method of Data Collection

Given the non-standard nature of the desired data, and following the method adopted by previous studies of similar themes (Delmas, 1999; Heiman & Nickerson, 2004; Kogut & Zander, 1993; Masten, 1984; Masten, Meehan, & Snyder, 1991; Monteverde & Teece, 1982; Poppo & Zenger, 1998; Robertson & Gatignon, 1998; Rosiello, 2003, 2007), it was decided that data for this research would be collected by survey.

Specifically, the survey is based on a questionnaire (see appendix I) designed to collect data on variables that are of interest to this research. Some of the questionnaire questions are adapted from previous literature (for example, Kogut & Zander, 1993); others are originally constructed to capture information on certain variables that are relatively underexplored (in particular, those associated with problem-solving approach in the KBV).

Three aspects of information have been collected. Firstly, respondents were asked to report—based on the definitions provided—the organization modes of their R&D projects that involve an international element[1]. Moreover, using multiple-item scales, respondents were asked to quantitatively evaluate certain underlying attributes (again, based on the definitions provided) of the R&D projects they reported. The respondent's perception of these attributes was measured by a five-point Likert scale, to which qualitative definitions were attached. In most cases, respondents were required to make subjective judgement regarding these attributes, or they were asked to agree or disagree with some statements. Finally, additional background information regarding the reported R&D project were also collected (mainly as control variables, e.g., the size, the nature of ownership, and the nationality/origin of the firm in which the R&D project was undertaken; information on the perceived performance of the reported R&D project was collected as well).

Both literature and the experience across the field suggest that the use of survey in similar research themes might encounter some practical difficulties. Specifically, obtaining survey response from executive is often problematic, and the response rates for R&D-related surveys are typically low[2] (Godin, 2002a, 2002b; Handke, 2007; Hansen, 2001; Mairesse & Mohnen, 2010; OECD, 2001; Poppo & Zenger, 1998; UNCTAD, 2005a; Xue, 2005; Xue & Liang, 2008).

Given these practical difficulties, a private consultancy/market research company that had strong business connections with the targeted industry was contracted to

[1] The "international element" is defined both in terms of geographic location and the origin of the participant(s).

[2] For example, in preparing World Investment Report 2005, UNCTAD used questionnaire to collect R&D-related data from the world's top R&D spenders. They reported that the response rate for their questionnaire was 22%, and they further commented that "relatively low response rates are not uncommon for R&D-related survey"(UNCTAD, 2005a: p. 3)

Xue and Liang's research (Xue, 2005; Xue & Liang, 2008) on foreign R&D labs in China might be an exception in this regard. They reported that in their research, 36 out of the 78 MNC directors in Beijing responded to their questionnaires (i.e., a 46% response rate).

We note that their research was supported by China's Ministry of Science and Technology, Ministry of Commerce, Ministry of Education, and Municipal government of Beijing, which, supposedly, explained the higher than usual response rate.

help distribute the questionnaire. Moreover, as the questionnaire is definition-intensive and might be taxing for some of the respondents[3], a structured interview questionnaire was apparently more appropriate than a self-administrated questionnaire. The same company also helped conduct part of the interviews using the questionnaire designed by the author.

A few notes regarding the implementation of the survey might be worth making.

(1) *Sectoral coverage:* To control for inter-industry difference, the sectoral coverage of the questionnaire is confined to the consumer electronics industry which includes (a) PC and peripherals, (b) mobile handset and other communication devices, (c) household appliances (white goods) and household audio-video equipment (brown goods).

(2) *Target response group:* The target response group of the questionnaire are key corporate informants who know the details of the project-level R&D activities of their company. Specifically, they are corporate executives in charge of the guidance and planning of their firms' R&D activities, current or ex-R&D directors, R&D project managers, senior R&D researchers and the like.

(3) *Sampling:* By screening their database for candidate companies for survey, the consultancy company produced a list of 314 companies which have been operating in the consumer electronics industry in mainland China and which might have participated in R&D activities that involve an international element. Given that small companies were less active in R&D, especially in international R&D[4] (Acs & Audretsch, 1988, 1991; Dosi, 1988; Fisher & Temin, 1973; Narula & Duysters, 2004; Shefer & Frenkel, 2005), an annual turnover of $2 million was set as the threshold for choosing candidate companies.

The survey then followed a rather standard procedure. Companies on the list were randomly selected, a senior executive in each selected company was tentatively contacted by telephone to inquire the possibility of participating in the survey. At first contact, they were clearly informed of the nature and objectives of this research[5],

[3] It could not always be expected that the respondent has the background training or the interest to tackle lengthy and abstract economic definitions of innovation used in the questionnaire.
[4] Previous studies suggest that a firm's propensity to invest in R&D, or to participate in international R&D alliance, is positively associated with its size.
[5] In particular, we emphasized that the nature of this research was purely academic, and the objective of this research is to explore how certain underlying attributes (in particular, knowledge-related characteristics) of a R&D project might shape the organizational choice of this problem-solving process.

strict confidentiality and willingness to share the results of the survey with them were also guaranteed[6]. If rejected, the surveyors moved on to phone the next company on the list until the pre-set sample size[7] was reached. In the sampling process, some minor adjustments were also made to make sure the sample size was (a) larger than 15 for all categories of ownership nature[8], and; (b) larger than 21 for all categories of organizational mode.

(4) *Response rate and non-response*: Before the overall sample size was reached, 96 companies on the list were randomly selected and tentatively contacted, among which 50 agreed to participate in the survey, making the overall response rate 52.1%.

For those companies who replied that they did not want to participate, the most common reasons provided in support of this decision were: (a) the contact did not perceive their company as (strictly) belonging to the consumer electronics industry[9]; (b) the company did not engage in R&D activity that involved an international element; (c) the respondent considered information concerning their R&D activities as too sensitive to be disclosed.

(4) *Structured interview:* For the 50 companies that agreed to participate, structured interviews based on the questionnaire were then arranged, in which the respondents were asked to give at least one example of a finished or almost finished R&D project that involved an international element. A subsequent series of questions then looked at the organizations modes and a set of multi-level attributes of the reported R&D project(s). Most of the interviews were conducted through on-site visits by trained surveyors[10]. Each questionnaire usually took 1–2 hours to complete. After the interview, follow-up contacts with 50% of the interviewees were made (on random basis) by a supervisor to verify the procedure and to double-check the validity of the

[6] As an incentive, the participating companies were also offered with an unpublished research report on this industry for free.

[7] With reference to studies of similar nature and theme (e.g, Rosiello, 2003), and given our budget constraint, the minimum size of our samples was set as 140 R&D projects.

[8] By their nature of ownership, the companies on the list could be classified under three categories, namely, Chinese firm, Chinese-foreign joint venture, and wholly-own subsidiary of a foreign firm. In the sampling process, we note that after two decades of FDI inflows in China, joint-venture has become increasingly less preferred than fully-owned subsidiary as a mode of entry. Probably for this reason, we find it a bit difficult to find enough samples for joint-ventures. Boutellier et al. (2008: p. 64) make similar observations.

[9] For example, a chipset company director reached by phone expressed that he perceived his company as belonging to semiconductor industry or microelectronics industry rather than consumer electronics industry, although some of their products were widely used in PC.

[10] Supplementary reading materials regarding the theoretical background of this research (in particular, a few key concepts and definitions used in our questionnaire) were provided to the surveyors. The author also ran a few email Q-A sessions to ensure that the surveyors had in-depth understanding of the few key definitions used in the questionnaire.

survey result. The author undertook part of the interviewing tasks in Beijing and South China, and accompanied the surveyors on some visits to ensure quality.

(5) *Multiple informants*. In the interview, each respondent was encouraged to report as many, and as diversified as possible their company's international R&D projects. However, given (a) the time-consuming and attention-demanding nature of the questionnaire, and; (b) that single informant is more likely to over- or under-report certain phenomena (Phillips, 1981), a multiple-informants (per company) arrangement was both more practical and efficient than a single-informant arrangement. Taking these into account, in our survey, the maximum number of projects reported by a single respondent was restricted to 3. If data for more than 3 R&D projects were to be collected from a single firm, multiple respondents were used to increase the validity and reliability of the data.

From the 50 companies that agreed to participate, 111 key informants were interviewed. Overall, they provided detailed information—in accordance with the requirements of the questionnaire—on 142 R&D projects that involved an international element. On average, each respondent reported information on 1.28 projects, and each participating company contributed 2.84 samples. Specifically, among the 50 participating companies, 3 companies (each) contributed 5 samples, 12 contributed 4 samples, 15 contributed 3 samples, 14 contributed 2 samples, and 6 companies contributed only 1 sample[11]; and among the 111 respondents being interviewed, 6 respondents (each) reported information on 3 R&D projects, 19 respondents reported 2 projects, and 86 respondents reported 1 project.

6.1.2 Sample Characteristics, Representativeness and Some General Background Information Regarding International R&D in Mainland China

To the best of my knowledge, there is very little systematic information regarding the overall status, or even certain critical dimensions (e.g., the overall scale, characteristics of participants, geographical and sectoral distribution, etc.) of international R&D activities in China, or in the Chinese consumer electronics industry.[12] [13] Nevertheless, the following information revealed by past studies might

[11] The numbers of samples collected from each company are roughly proportionate with their R&D expenditure. For example, the 3 companies that contributed 5 samples, Nokia, Huawei, and Sony, are amongs the most R&D active companies in this industry.

[12] This could be attributed, in the first place, to the fact that international R&D is a relatively new phenomenon in China; moreover, it is also attributable to the difficulties of doing rigorous research in China.

[13] An UNCTAD survey on the world's largest R&D spenders (UNCTAD, 2005) showed that, by 2004, China had become the third most important offshore R&D location, ranking only after the United

be indicative and can be used as a benchmark to evaluate the representativeness of our samples.

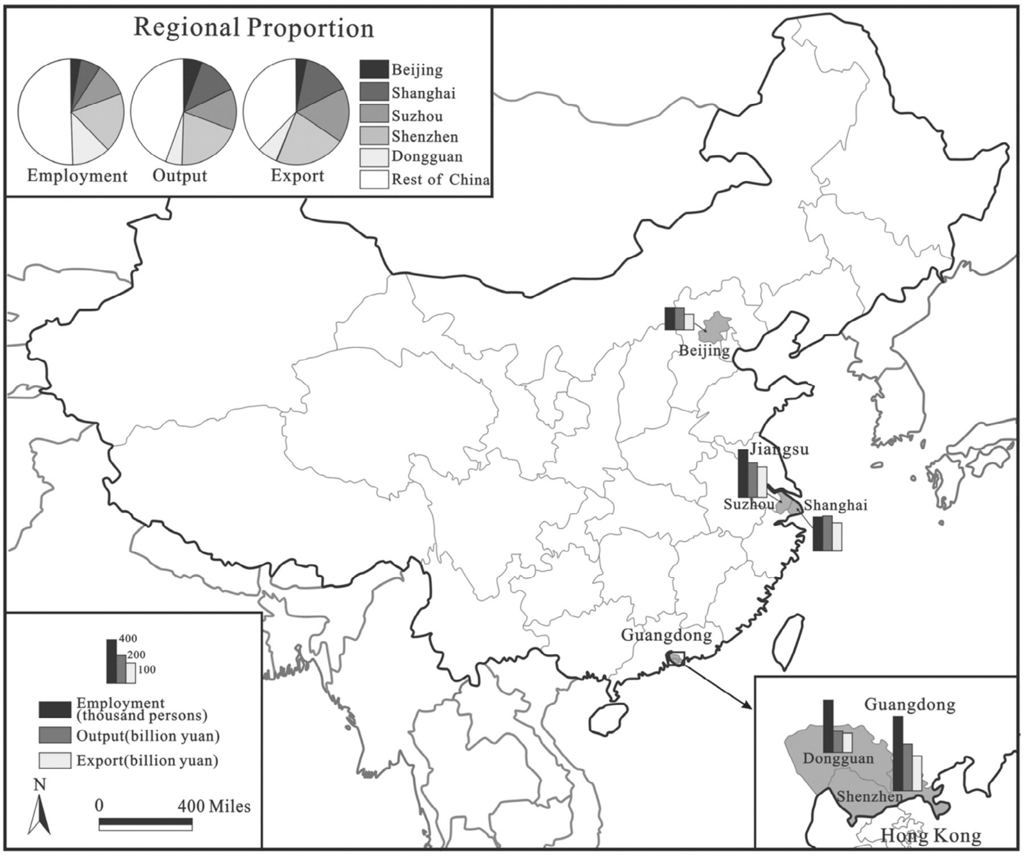
Prior studies (Dedrick & Kraemer, 2008; Y. Zhou, Sun, Wei, & Lin, 2010) and industrial reports (AccessAsiaLtd., 2008; CCIDConsulting, 2010)[14] revealed that most of the manufacturing activities in the Chinese consumer electronics industry are highly concentrated[15] in the following three mega-city regions (see Figure 6-1-1), namely, Pearl River Delta (PRD) (centered around Shenzhen–Dongguan) and, to a lesser extent, the Yangtze River Delta (YRD) (centered around Shanghai–Suzhou), and the Bohai-Rim (centered around Beijing-Tianjin).

States and the United Kingdom. It should nevertheless be noted the ranking of locations were measured loosely in terms of number of times mentioned by the respondents, therefore it only indicated where companies were performing R&D but not how much R&D was being carried out.
According to Chinese authority (Ministry of Science and Technology, MOST), by 2005, there were over 750 foreign R&D centres in China. This figure, according to Boutellier et. al. (2008: p. 62), was second only to the US. An even recent estimate of the number of foreign R&D centres was 980 by 2006 (Ministry of Commerce, MOFCOM). However, Denis Simon et al. (2007) noted that this number might be overstated.

[14] The sectoral coverage of these studies overlap with, but are somewhat different from our study. However, their findings are highly consistent.
Zhou et al.'s study (2008) focus on the *ICT industry*, which covered (a) hardware manufacturing including manufacturing of computer/communication equipment (Chinese SIC 401 and 404); (b) semiconductors (SIC 4052 and 4053); (c) electronic parts manufacturing excluding semiconductors (4051, 406) and; (d) software (SIC 62). Access Asia Ltd's report reviews trends and developments over 2002 to 2008 in China's *consumer electronics industry*. Their definition of consumer electronics industry does not include computers and peripherals, and communications technology. Dedrick & Kraemer's study focus exclusively on the *PC industry*.

[15] According to Zhou et al. (2010), although Beijing, Shanghai–Suzhou, and Shenzhen-Dongguan occupy only a tiny portion of the total territory of China, together they accounted for half of China's ICT manufacturing employment and close to 60% of its ICT manufacturing output and export in 2004.

Figure 6- 1- 1: Three ICT Manufacturing Hubs in China



Adopted from Zhou et al. (2010, p. 3, Figure 1), whose data are based on the 2004 Chinese national census (National Bureau of Statistics of China, Economic Census Office, 2006).

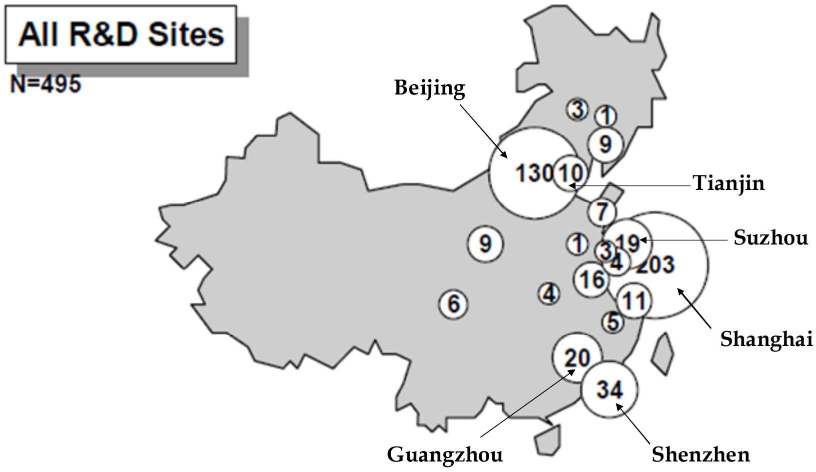
The location of R&D activities in this industry is somewhat different. In the past two decades, with MNCs being the key driving force, China's manufacturing sector in general and consumer electronics industry in particular has witnessed a rapid globalization process of innovation (Boutellier, Gassmann, & Zedtwitz, 2008; Dedrick & Kraemer, 2007; Lundin & Schwaag Serger, 2007; Sun, Zedtwitz, & Simon, 2007; UNCTAD, 2005; K. Walsh, 2003; Xue, 2005; Xue & Liang, 2008). Being part of this process, a big proportion of R&D activities in this industry can be related to MNCs' R&D presence in China, either independently or in cooperation with indigenous firms and institutions (Bruche, 2009; Cai, Todo, & Zhou, 2007; Y.-C. Chen, 2006, 2007; Li & Yue, 2005; Moris, 2004; Sun, 2002; Sun & Du, 2011; Sun et al., 2007; Wei, Zhou, Sun, & Lin, 2009; Zedtwitz, 2005). The innovative dynamics and the interaction between foreign and indigenous firms have been well-documented for the segment of PC and peripherals (S.-H. Chen, 2004; Dedrick & Kraemer, 2003, 2005, 2006; Dedrick, Kraemer, Linden, Brown, & Murtha, 2007; Ernst, 2006, 2008, 2009; Lu & Liu, 2004; Luethje, 2004; Shin, Kraemer, & Dedrick, 2009), and to a lesser extent, for the segment of mobile handset and personal communication devices (Y.-C. Chen & Vang, 2008; Dedrick, Kraemer, & Linden, 2011; Ernst & Naughton, 2008; P. Fan, 2006, 2010a, 2010b; Xie & White, 2006).

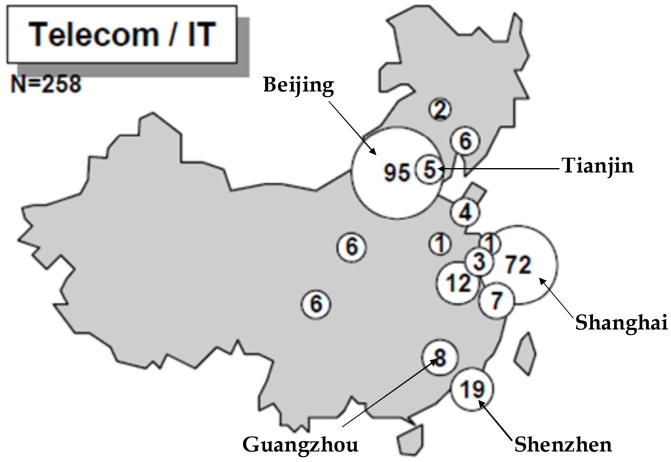
Studies reveal that the majority of foreign R&D facilities in China are predominantly concentrated in Beijing and Shanghai[16], with Tianjin, Suzhou and the Southern Cantonese cities of Guangzhou, Shenzhen as second-tier R&D locations (see Figure 6-1-2 and Figure 6-1-3) (Boutellier et al., 2008; Y.-C. Chen, 2006; Y.-C. Chen, Vang, & Chaminade, 2008; Sun, 2009; Sun, Du, & Huang, 2006; Zedtwitz, Ikeda, Gong, Carpenter, & Hamalainen, 2007). It has also been found that R&D units with a research mission tend to locate themselves in Beijing, whereas development laboratories prefer to choose a location in or in the vicinity of Shanghai (Y.-C. Chen, 2008; Motohashi, 2010; Zedtwitz, 2004).

Given these background information, and to the best of our knowledge, we believe our sample is more or less representative of the population, especially along the following few critical dimensions (see Table 6-1-1 to 6-1-4, Figure 6-1-3 to 6-1-6).

[16] According to Boutellier et al. (2008), by Sep. 2006, of all the 495 foreign R&D labs in China (GLORD database, Tshinghua University), 67% are located in Beijing and Shanghai alone.

Figure 6- 1- 2: Geographical Distribution of Foreign R&D Labs in China in 2006[17][18]





Adopted from Boutellier et al. (2008), p. 68, Fig. I.3.2. and Zedtwitz et al. (2007), p.22, Figure. 2, based on 495 foreign R&D units with exact location data (GLORD database, Tsinghua University).

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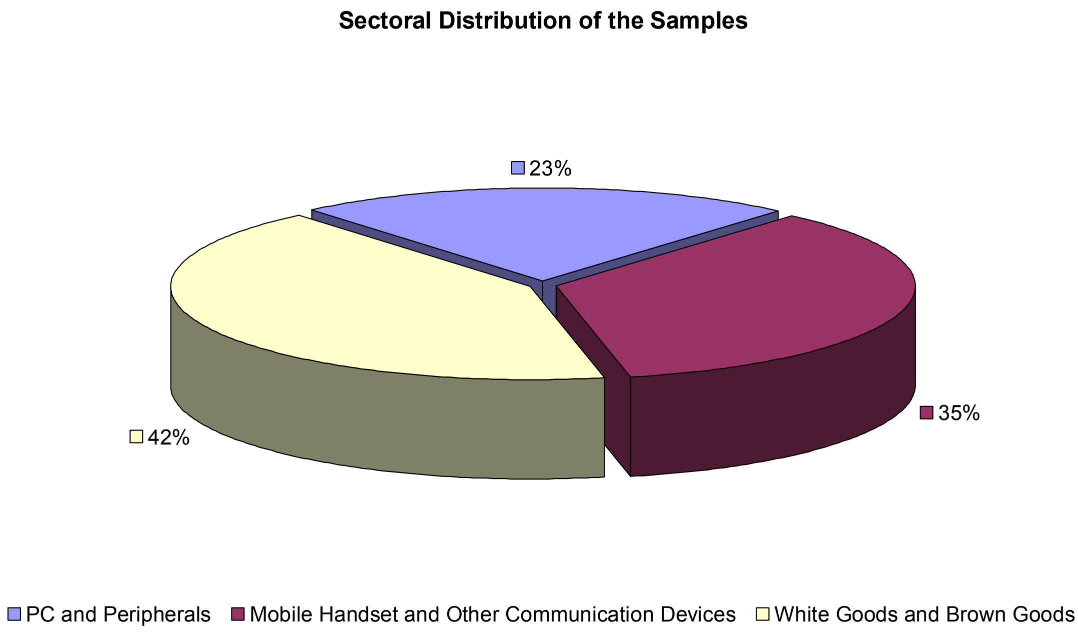
[17] Data are updated to Sep. 2006.

[18] Boutellier et al.(2008) separated all the 495 foreign R&D labs listed in the GLORD database into 4 industrial groups: telecom/IT (including software) (258 labs), food (17 labs), pharmaceutical/chemical (81 labs) and all others. The coverage of their telecom/IT category includes but is broader than the "consumer electronics industry" as we define it.

Table 6- 1- 1 & Figure 6- 1- 3: Sectoral Distribution of the Samples[19]

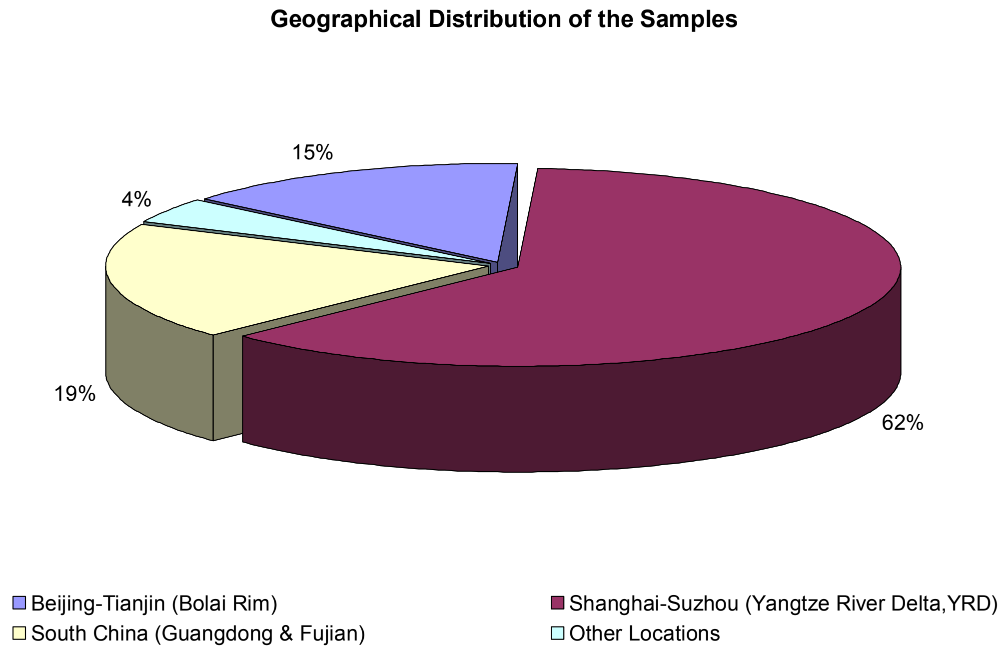
SECTOR	NUMBER OF CASES	%
PC and Peripherals	32	23%
Mobile Handset and Other Communication Devices	50	35%
White Goods and Brown Goods	60	42%



[19] It is less clear what the overall sectoral distribution of the international R&D activities in China really is. The best available information might be that from Xue (2005). According to Xue, by 2004, the sectoral distribution of 107 autonomous R&D labs set up in China by Business Week 1000 MNCs is as follows:
software (23%), telecommunications (18%), semiconductors (13%), industrial equipments and components (5%), automobiles (7%) commodity chemicals (7%) biotechnology & drags (6%), household electronics (6%), other IT products (5%), chemicals (4%), food and beverages (3%), industrial conglomerates (2%), others (1%).
Although his classification of sectors is not fully compatible with ours, it could still be identified that the three sectors covered in our research are among the most active sectors in terms of their international R&D activities.
The above-mentioned UNCTAD survey (UNCTAD, 2005) also confirm that by 2004, electronic & electrical and IT hardware industries are the two most important industries in terms of MNCs' R&D presence.

Table 6- 1- 2 & Figure 6- 1- 4: Geographical Distribution of the Samples[20]

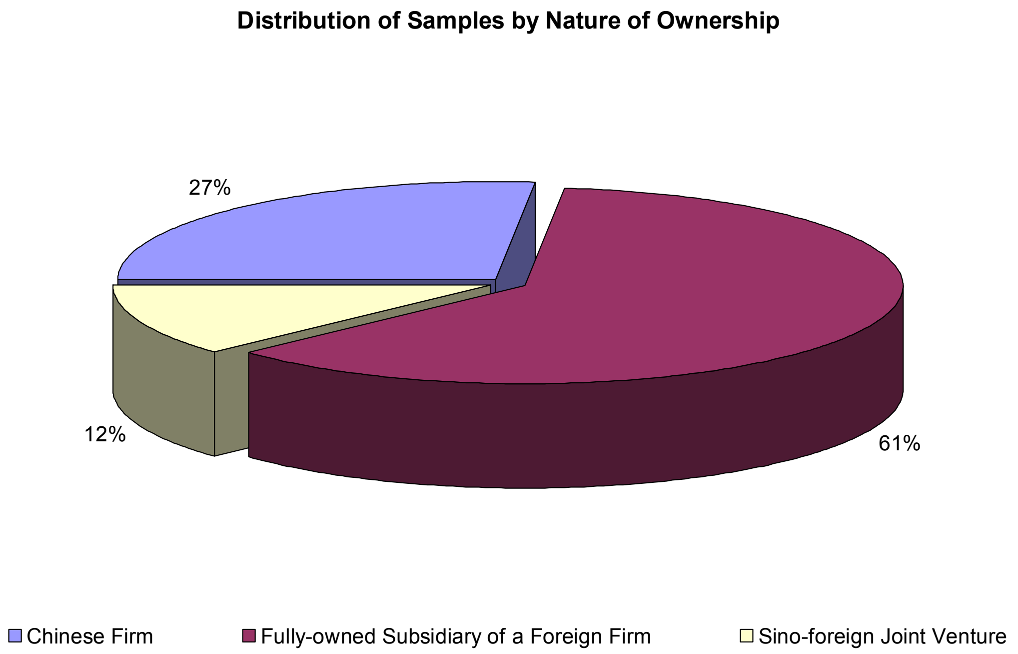
GEOGRAPHICAL LOCATION OF REPORTED R&D PROJECT	NUMBER OF CASES	%
Beijing-Tianjin (Bolai Rim)	21	15%
Shanghai-Suzhou(Yangtze River Delta, YRD)	88	62%
South China (Guangdong & Fujian)	27	19%
Other Locations	6	4%



[20] Boutellier et al.(2008) report that, of the 495 foreign R&D labs set up in China (by Sep. 2003), 203 are located in Shanghai (41%), 130 in Beijing (26%), and 34 in Shenzhen (7%). Among these 495 labs, 258 labs are from Telecom/IT industry (including software), of which 95 located in Beijing (37%), 72 in Shanghai (28%), and 19 in Shenzhen (7%).
Xue's finding is similar. According to him (Xue, 2005), by the end of 2004, the geographical distribution of the 107 autonomous labs set up by Business Week 1000 MNCs in China is as follows: Beijing (47%), Shanghai (33%), Tianjin (2%), Guangdong (7%), Jiangsu (5%), Other Regions (5%).
Zedtwitz (2004) reports that foreign R&D labs in Beijing tend to concentrate in telecommunication and industrial equipment, while those in Shanghai show much more diversity and tend to be from more consumer-oriented industry.
Dedrick & Kraemer's research (2008) reveals that most of the R&D activities in the Chinese PC industry concentrate in Yangtze River Delta centred around Shanghai.
The private consulting company assisting us with the data collection is Shanghai-based; it is therefore likely that R&D undertaken in this region might be oversampled.

Table 6- 1- 3 & Figure 6- 1- 5: Distribution of Samples by Nature of Ownership[21]

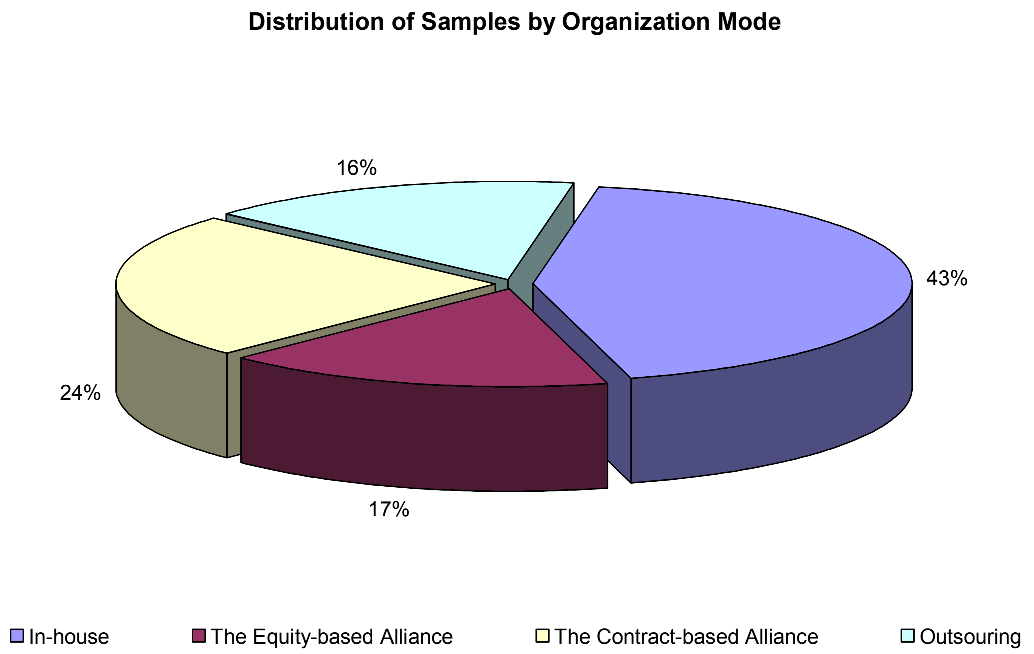
NATURE OF OWNERSHIP	NUMBER OF CASES	%
Chinese Firm	38	27%
Fully-owned Subsidiary of a Foreign Firm	87	61%
Sino-foreign Joint Venture	17	12%



[21] It is even less clear how international R&D activities are distributed by participant's nature of ownership. To the best of our knowledge, there is only scattered information in this regard. According to Xue (2005), of the 215 R&D units set up by Business 1000 MNCs in China, 107 are autonomous labs, 59 are R&D units in the local subsidiaries and 49 are cooperative centres (with university and so on).

Table 6- 1- 4 & Figure 6- 1- 6: Distribution of Samples by Organization Mode

ORGANIZATION MODE	NUMBER OF CASES	%
In-house	61	43%
The Equity-based Alliance	24	17%
The Contract-based Alliance	34	24%
Outsourcing	23	16%



6.2. The Variables (Definition and Measurement) and the Hypotheses

In this section, we will explain how the dependent and independent variables in this research are defined and measured.

6.2.1 Dependent Variable

In this research, the dependent variable—***organization mode***—is being treated as an unordered discrete variable. On the basis of the collected data, we will try to find out how the firm chooses among a limited set of different organizational modes to minimize the expected costs of governing a R&D project (or equivalently, to maximize the net benefits of a R&D project).

In the existing literature, the organizational modes of the firms' R&D activities are broadly classified into three categories, i.e.: in-house, collaborative arrangements and outsourcing (arm's-length like contract) (Narula, 2001a, 2001b; Richardson, 1972; Robertson & Gatignon, 1998)[22]. In the category of collaborative arrangements, contract-based and equity-based collaborative arrangements are often further differentiated (Hagedoorn, 1990; Pisano, 1989, 1990, 1991). Summing up, if we label the above four organizational modes as 1 to 4 respectively, the dependent variable could take any of the four possible values.

The four organizational modes are defined as follows.

A. In-house

In the case of ***in-house***, the firm undertakes the R&D project internally.

B. Outsourcing

In the case of ***outsourcing***, the firm, with a view to find a solution for its technological problem, contracts out a R&D project to some other organization.

It should be noted that when a R&D project is organized by this mode, it is essentially a cash-for-technology exchange which approximates an arm's-length contract. In this circumstance, the flow of knowledge is unilateral and the knowledge is often in highly codified or symbolized forms (e.g. blueprint, recipes, or components embodying the solution). Relatedly, the solution is often of ready-to-use,

[22] The origin of such a three-categories classification could probably be traced back to Richardson (1972: p. 890), who notes that "co-ordiantion (of complimentary activities) can be effected in three ways; by direction, by co-operation, or through market transactions"

off-the-shelf nature and could generally be integrated into the firm's existing system of operation with little or no adaptation. A unilateral technological license, by which the licensee firm acquires a ready-to-use solution for a specific problem, is also included as a form of outsourcing.

C. Collaborative Arrangements

Collaborative arrangements (also known as "alliance") refer to a wide variety of 'hybrid'[23] organization modes often said to be lying somewhere between in-house and pure arm's length market transaction (Williamson, 1985b, 1990, 1991). Under this category, a further differentiation between ***contract-based collaborative arrangements*** and ***equity-based collaborative arrangements*** is often made. (Hagedoorn, 1990; Pisano, 1989, 1990, 1991).

In the former category (***contract-based collaborative arrangements***), partner firms, by setting up a binding agreement, combine their respective resources (in particular, technological expertise) in a collaborative R&D project, but the agreement does not involve equity exchange in any sense. It should also be noted that in a contract-based collaborative arrangement, the knowledge flow is quite different from that in a pure arm's-length contract. In the former case, there are substantial knowledge exchanges between the partner firms, while in the later, the knowledge flow is basically unilateral.

A second category of collaborative arrangements is that of ***equity-based collaborative arrangements***. Under such arrangements, the partner firms refer to equity-based arrangement as an umbrella structure to support their joint R&D project.

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[23] The drawback of the terminology is obvious in that it carries a connotation that these "hybrid" forms could be interpreted as a simple combination of the ingredients coming from the pure forms of arm's length market exchange and hierarchies (Kay, 1997; Menard, 2010). Put differently, by this term, a linear relation between market, collaborative agreements and internal organization (hierarchies) is often assumed. Such presumption is highly problematic. As have been indicated by various authors (e.g., Atik, 1995), these "middle case" organization modes are far from being blended case but instead distinct types of organizational modes for their own sake. For example, Kay (1992, 1997) argues forcefully that joint venture is typically plagued by the problem of being the servant of two (or more) masters, which generate contractual, control and appropriability problems that all tend to exacerbate transaction costs relative to pure hierarchical solution. In other words, joint venture carries the burden of both hierarchical and market arrangements, making its transaction (coordination) costs greater than that for the corresponding pure forms. Much of the organizational and managerial literature also confirm that joint venture is often viewed by the managers as the most expensive mode of organizations, a last resort dominated by other modes of organizing inter-corporate activity (for a 1980's view, c.f. Berg, Duncan, & Friedman, 1982, for a recent view, c.f. Brechbuhl, 2006). In short, it is hard to conceive of a rationale for the evolution and proliferation of joint venture activities purely on the basis on transaction cost reasoning, and it might be misleading to treat joint venture—presumably the most important "hybrid" mode—as lying somewhere in between the polar modes of arm's length market contract and hierarchy along some hypothetical spectrum, as it is asserted by the standard transaction cost interpretations (Williamson, 1985, 1990, 1991).
For the above reasons, the author has resisted using the term "hybrid" to describe collaborative arrangements, and on the same ground, the author believes that the dependent variable in this research should be treated as an unordered discrete variable.

Specifically, the partner firms could either jointly invest in and set up a joint venture (whether it be a manufacturing joint-venture or R&D joint-venture), and then undertake joint R&D projects in this new legal entity, or they could alternatively take/cross-take minority equity stakes to support the collaboration of their joint R&D project.

In short, for the purpose of this research, the organizational modes of the firms' R&D activities are classified in the following manner (see table 6-2-1).

Table 6- 2- 1: The Organizational Modes of the Firms' R&D activities

Organizational Mode	In-house	Collaborative Arrangements		Outsourcing (Arm's-length Like Contract)
		The equity-based Collaborative Arrangement	The contract-based Collaborative Arrangement	
Examples	Wholly-owned subsidiary (either manufacturing , marketing, or R&D oriented)	production Joint venture (in which joint R&D projects are undertaken); R&D joint venture	Co-development contract; Bilateral licensing	Unilateral licensing; R&D outsourcing contract; OEM; ODM

6.2.2 Independent (Explanatory) Variables

For the purpose of this research and with reference to previous studies on similar subjects, twelve explanatory variables are initially included. Data on these variables were collected by questionnaire (see appendix I). Unless otherwise stated, they were measured using a 5-point Likert scale.

A. Problem Structure (PS)

This variable was formally introduced in the empirical literature by Macher (2006) from a problem-solving approach within the knowledge-based view. Following Simon (1973) , Macher argues that the few generic organization modes differ systematically in terms of their relative capabilities to organize different approaches of solution search (directional vs. heuristic), which, in turn, depend critically on the structure of the problem to be solved (i.e. ill-structured vs. well-structured problem). A discriminating alignment can thus be worked out so as to achieve a match between organization modes and the structures of the problems to be solved.

Following Macher (2006), a well-structured problem is defined as one with a clear boundary of the relevant knowledge sets; and the interaction among these knowledge sets are well-understood; consequently, there are explicit and widely-accepted approaches for solving the problem.

Conversely, for an ill-structured problem, the boundary of the relevant knowledge sets is ambiguous, and the interactions between the relevant knowledge sets are poorly understood, sometimes these interactions are unexpected or unknown; consequently, no widely-accepted approach exists for solving the problem.

In the questionnaire, problem structure (PS) is measured in such way that as the value of PS increases from 1 to 5, the problem tends to be more ill-structured.

B. Complexity (COM) and Decomposability (DEC)

These two dimensions are introduced by Marengo *et al*. (L Marengo, G Dosi, P Legrenzi, & C Pasquali, 2000) and Nickerson and Zenger (2004) in the context of developing a problem solving approach to the boundary determination of the firm. Again, the origin of these ideas can be traced back even earlier to Simon (1962).

According to the proponents of problem-solving approach (Nickerson et al., 2007; Nickerson & Zenger, 2004), efficient solution search depends on the complexity/non-decomposability of the problem, the extent to which non-decomposability generates hazards that impede knowledge-formation, and the relative efficacy of various organization modes in implementing solution searches appropriate for the level of problem complexity. Some problems can be effectively solved through the combination of independent, modular searches, which require little organizational control. Other problems require extensive knowledge sharing across actors as well as coordination in the searching process. For such problems, various collaborative forms or hierarchy are both more effective in managing the attendant knowledge formation hazards and more efficient in organizing the solution search.

Although the complexity and decomposability of a problem are conceptually highly correlated, we still deem it worthwhile to try to empirically differentiate their respective effects. In this research, complexity and decomposability are treated as two variables.

B.1. Complexity (*COM*)

Following the problem solving approach literature (Brusoni, Marengo, Prencipe, & Valente, 2007; Macher, 2006; L Marengo et al., 2000; Nickerson et al., 2007; Nickerson & Zenger, 2004), the degree of the complexity of a problem is defined in the following way:

A simple problem involves very few knowledge sets, and the interactions/interdependences between the knowledge sets are limited and low.

Conversely, a complex problem involves a large number of knowledge sets; and the interactions/interdependences between these knowledge sets are extensive and high.

B.2. Decomposability (DEC)

Relatedly, the degree of decomposability of the problem is defined in the following way:

A decomposable problem is one that can be subdivided into sub-problems; each of the sub-problems draws from rather specialized knowledge sets and could therefore be solved quite independently.

Conversely, a non-decomposable problem cannot be subdivided, as the knowledge sets interactions within the problem are so extensive that it is virtually impractical to define sub-problems and to discover corresponding subordinate solutions in a way that could offer predictable improvements over random trials. For such problem, if a solution is to be found, it has to be an overall solution.

In the questionnaire, Complexity (COM) is measured in a way that an increase in the value of COM implies a higher degree of complexity of problem to be solved; while an increase in DEC indicates that the problem to be solved tends to be less decomposable.

C. Existing Knowledge Base (EKB)

One of the fundamental insights of the knowledge-based view is that idiosyncratic firm capabilities are the key shaper of the firm's boundary (Penrose, 1959; Richardson, 1972). Specifically, the firm vertically[24] integrate into activities in which

[24] Similar line of reasoning (to be more exact, a combination of resource-based and transaction cost reasoning) could be applied to the determination of the horizontal boundaries (scope) of the firm. Specifically, it is argued (Penrose, 1959) that through various learning processes, existing activities within a firm are routinized, excess resources are released and knowledge accumulates. These, in turn, could be used as a stepping stone for related diversification. The firm, in this view (Teece, 1980; 1982;

they have relatively superior capabilities and outsource those in which they have inferior capabilities (Argyres, 1996; Jacobides & Hitt, 2005; Jacobides & Winter, 2005; Madhok, 2002; Poppo & Zenger, 1998). Recent researches (Bruce & Jack, 2002; Contractor & Lorange, 2002; Contractor & Ra, 2002; Coombs & Metcalfe, 2000; Grant & Baden-Fuller, 2004; Harrison, Hitt, Hoskisson, & Ireland, 2001) also suggest firms participate in various forms of alliance with a view to get access to knowledge/capabilities they need but don't have.

In the context of current research, we believe that a firm's existing knowledge base plays a critical role in shaping the organizational choice of its R&D activities. Specifically, following the logic of the problem-solving approach, a R&D project undertaken by a firm is deemed as an attempt to find a solution for a valuable problem (Heiman & Hurmelinna-Laukkanen, 2010; Macher, 2006; Macher & Boerner, 2011; Nickerson et al., 2007; Nickerson & Zenger, 2004). When a firm possesses most, if not all, of the relevant knowledge/capabilities that are required to solve a problem, it tends to organize the R&D project internally. Conversely, when a firm has little background knowledge in the relevant fields of a problem it wants to solve, it tends to refer to external sources for finding a solution (i.e., outsource the R&D project). Between these two extremes, a firm would—depending on the attributes of the problem under consideration—leverage various kinds of collaborative arrangements to get access to external knowledge/capabilities that are required to solve the problem. This is most obvious when a firm is trying to solve a complex problem, for which it has considerable knowledge base but is nevertheless less familiar with some critical part of the relevant knowledge sets.

In this research, EKB is designed to measure a firm's existing knowledge base for a R&D project. *Specifically, it is defined as the extent to which a firm possesses all the relevant knowledge/capabilities that is required to solve the problem at the time of project initiation.*

As the value of EKB varies from 1 to 5, the firm tends to have increasingly complete knowledge/capabilities that are required to solve the problem under consideration.

D. Tacitness of Knowledge

It has been long argued in the knowledge-based literature that the tacitness of knowledge has profound impacts on organizational choices. Following Winter's

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Teece et al., 1994), tends to diversify horizontally into related activities that build upon or extend existing capabilities rather than contract out its underutilized assets and excess capabilities.

taxonomy of knowledge (Winter, 1987) and Kogut and Zander's definition (Kogut & Zander, 1993; Zander & Kogut, 1995), the tacitness of knowledge is operationalized and measured from the following two dimensions, namely, codifiability, teachability.

D.1. Codifiability (COD)

Codifiability is defined as the extent to which one can easily find relevant reference materials (books, blueprints, and manuals etc., either in printed or electronic form) that could deliver to a new team member—which is of average competence and with adequate training in relevant fields—most of the critical knowledge in an accessible way. In case such reference materials are not available for the time being, to what extent it is an easy job to prepare such materials by converting the relevant knowledge into codified format—say, in the form of internal training materials—if such practice turns out to be necessary.

D.2. Teachability (TEA)

Relatedly, teachability is defined as the extent to which it is an easy job for a new team member—which is of average competence and with adequate training in relevant fields—to learn the core knowledge and skills that are required to solve the problem, by working with and being mentored by a skilled team member.

In the questionnaire, codifiability (COD) and teachability (TEA) are measured in such a way that the higher the value of COD is, the less codifiable (more tacit) the relevant knowledge is; and the higher the value of TEA is, the less teachable (more tacit) the relevant knowledge is.

E. Social Distribution (Dispersion)[25] of Knowledge (SDK)

In addition to the dimension of tacitness, social distribution (dispersion) of knowledge has also been identified as a critical attribute with substantial organizational ramifications.

[25] In the dictionary, "distributed" and "dispersed" have similar meaning; and in the knowledge-based literature, the two terms "distributed knowledge" and "dispersed knowledge" are also used interchangeably in most of the cases. However, for certain *historical* reason, some authors (e.g., Becker, 2004) have tried to make a distinction between the two terms. Specifically, "distributed knowledge" is said to denote a situation where different people hold overlapping common knowledge (in particular, they know who knows what), whereas "dispersed knowledge"—a term used by Hayek (1945) in his seminal contribution—is defined to connote a situation of specialization and complementarity where there could be very little overlapping between the knowledge held by different people. The author notes the distinction but will still treat these two terms indifferently in this study.

The notion of distributed knowledge[26], first articulated[27] in the field of computer science in the 1980s' (Halpern & Moses, 1990), has ever since been adopted in the knowledge-based literature and further developed into one of its central constructs (K. Foss & Foss, 2009). Specifically, productive knowledge is often socially distributed (Langlois & Foss, 1999; Marengo, 1995; Spender, 1998; Tsoukas, 1996), i.e., knowledge required to perform a specific task is often not possessed by any single mind, but instead distributed among a group of interacting agents, emerging from the aggregation of the (possibly tacit) knowledge elements of these interacting individuals. Moreover, such knowledge is often firm-specific in the sense that it can only be mobilized in the firm-specific context of carrying out a multi-person productive task; therefore, some sort of qualitative coordination is often required for its efficient utilization.

For the purpose of this research, the degree of social distribution (dispersion) of knowledge is defined as the extent to which the knowledge required to solve the problem is possessed by one or few individual experts; or on the contrary, such knowledge are widely distributed among a group of experts such that there isn't any single expert can solve the problem on his own. In the later case, even if one or few skilled team member leave the team, the progress of the R&D project under consideration would not be seriously hindered or slowed down.

In this research, variable SDK is designed to measure the degree of social distribution of the relevant knowledge. As the value of SDK varies from 1 to 5, the underlying knowledge tends to be more socially distributed.

F. Uncertainty and Asset Specificity

[26] It should be noted that the emphasis of the concept of "distributed knowledge" is different from what is known as "distributed capabilities" or "distributed innovation processes" in the literature (Coombs and Metcalfe, 2000; Howells et al., 2003). In our case, the emphasis is on socially contextualized, firm-specific, collective knowledge which are hard to dismantled from the firm's existing structure. In the later case, the emphasis is more on the fact that as a result of the increasing complexity of the technology, it has been less frequent that the capabilities required for some substantial innovations are readily located within a single firm; rather, they are usually distributed/dispersed *across* firms and other knowledge generating institutions. Accordingly, the firms tends to refer more often to the range of cooperative arrangements for accomplishing this 'distributed innovation process'.

[27] Surely, social distribution of knowledge can be related to the concept of "routine" popularized by Nelson and Winter' highly influential "An Evolutionary Theory of Economic Change". According to Nelson & Winter (1982), routines are fundamentally collective phenomena which involve the knowledge/cognition of multiple actors (Nelson and Winter, 1982: p. 73). Such understanding has been firmly rooted in the literature (Becker, 2004). For example, the definition given by Cohen et al. (1996: p. 683), which probably best captures the essence of current understanding of this concept, states that routine is "... an executable capability for repeated performance in some context that has been learned by an organization in response to selective pressures".

Asset specificity and uncertainty have long been identified by transaction costs theorists (Williamson, 1985, 1996) as two of the most critical transactional attributes that shape the organizational choice (or in the parlance of Williamson, the choice of governance mechanisms). In this research, the three variables *DUN*, *HAS* and *PAS* are designed to capture the respective impact of *demand uncertainty*[28]*, human asset specificity and physical asset specificity* on the choice of organizational modes.

The definitions of demand uncertainty and asset specificity have been rather standard in the transaction costs literature. Specifically, their definitions are given as follows.

F.1. Demand Uncertainty (DUN)

In the context of current research, demand uncertainty (Robertson & Gatignon, 1998; G. Walker & Weber, 1984) is defined as *the extent to which it is a difficult job to forecast—with certain precision—the future demand of product/service to which the R&D project under consideration is intended to contribute.*

In the questionnaire, DU is measured in a way that as the value of DU varies from 1 to 5, the future demand of the product/service to which the R&D project is intended to contribute tends to be increasingly more difficult to forecast.

F.2. Human Asset Specificity (HAS)

Given that the central focus of our research is the organization of R&D activities, two distinct types of asset specificity (S. Klein, Frazier, & Roth, 1990; Williamson, 1983) are of particular relevance and should therefore be differentiated, namely, *human asset specificity* (*HAS*) and *physical asset specificity* (*PAS*).

In the context of this research, human asset specificity is defined as the extent to which the skills and knowledge gained/developed/accumulated in the R&D project under consideration are still useful outside this project.

F.3. Physical Asset Specificity (PAS)

In the context of this research, physical asset specificity is defined as the extent to which the investment in physical assets that are required to support the R&D project under consideration is redeployable outwith this project.

[28] The distinction between demand uncertainty and technological uncertainty was first suggested by Abernathy(1978) and formally specified later by Walker and Weber(1984). In the context of this research, technological uncertainty has been captured by those variables associated with problem complexity.

As the value of HAS and PAS increase, the human and physical asset specificity of the R&D project tend to increase respectively.

G. Appropriability (AP)

Apart from asset specificity, "appropriability", or the possible leakage of valuable intellectual property, has also been widely accepted in the transaction costs literature as an attribute with clear organizational implications (Buckley & Casson, 1976; Oxley, 1997; Teece, 1986). Specifically, when valuable knowledge is involved in a transaction, the incentives for sharing knowledge are plagued by a well-known paradox—the value of knowledge to its potential acquirer is not known until it is revealed; however, once the knowledge is revealed, the potential acquirer has no need or at least less incentive to pay for it (Arrow, 1962, 1973). Property rights and complicate contract design may provide some degree of protections in this circumstance, however, cognitive limitations, together with costly law enforcement, have made such contractual protections hard to verify, difficult to draft, and costly to implement. Overall, the implication is—opportunism in knowledge exchange discourages knowledge sharing; to avoid unauthorized appropriation and to prevent the dissipation of appropriable rent, highly appropriable knowledge should be utilized under unified governance.

In this research, the following two questions are designed to capture the appropriability of the relevant knowledge:

(1) To what extent the result of the R&D project under consideration can be easily imitated by an outsider, say, by reverse engineering or inventing around, and;

(2) In case one or few R&D team members leave your company and work for your competitor, how likely it is the event would lead to substantial leakages of the relevant knowledge to your competitor.

As the value of the response to each of the two questions varies from 1 to 5, the degree of appropriability of the underlying knowledge tends to increase.

6.2.3 The Hypotheses

On the basis of the review of relevant theoretical and empirical literature in previous chapters (in particular, chapter 4 and chapter 5), we now list the hypotheses that will be tested in the following sections.

These hypotheses are concerned with the effects of the explanatory variables on the choice of organizational modes of the problem-solving (i.e., R&D).

A few points might be worth noting.

Firstly, in the existing literature, it is generally held that collaborative arrangements (i.e., alliances) are hybrid modes of organization lying somewhere between the polar modes of arm's length market contract and hierarchy along a hypothetical continuum. This means, as far as the effects of an explanatory variables are concerned, its impact on the probability of choosing alliance is always lying somewhere between its impact on the probabilities of choosing in-house and outsourcing. To be more exact, if a higher value of an explanatory variable ***V*** favours the choice of in-house over outsourcing, it could be inferred that when the choice is to be made between in-house and alliance, a higher ***V*** would favour the choice of in-house, and when the choice is to be made between alliance and outsourcing, a higher ***V*** would favour the choice of alliance.

Secondly, with the two forms of alliance being further differentiated, it is also held that equity-based alliances are more hierarchical than contract-based alliances. This means, the whole set of organizational modes along the market-hierarchy continuum are: outsourcing (i.e, market), contract-based alliance, equity-based alliance and in-house (i.e., hierarchy). More hypotheses regarding the choice of a specific pair of organizational modes could thus be inferred whenever necessary.

Thirdly, as we are more concerned [29] with the choices between in-house vs. outsourcing, and in-house vs. alliance, we focus the hypotheses regarding these two choices.

Finally, when the two types of alliance are further differentiated, we are particularly interested to see whether the effects of certain variables on the probabilities of choosing these two distinct types of alliances are of different patterns.

Below, we list the hypotheses that will be tested.

[29] From a theoretical point of view, the choice between alliance and outsourcing is less interesting.

A. Hypotheses Regarding the Complexity of the Problem

H_A^1: *The more **ill-structured** a problem is, the more likely the problem-solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_A^2: *The more **ill-structured** a problem is, the more likely the problem-solving will be organized through in-house rather than by alliance, ceteris paribus.*

H_B^1: *The more **complex** a problem is, the more likely the problem-solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_B^2: *The more **complex** a problem is, the more likely the problem-solving will be organized in-house rather than by alliance, ceteris paribus.*

H_C^1: *The more **decomposable** a problem is, the more likely the problem-solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_C^2: *The more **decomposable** a problem is, the more likely the problem-solving will be organized in-house rather than by alliance.*

B. Hypotheses Regarding a Firm's Existing Knowledge Base

H_D^1: *The higher **a firm's existing knowledge base** in relevant fields, the more likely the problem solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_D^2: *The higher **a firm's existing knowledge base** in relevant fields, the more likely the problem solving will be organized in-house rather than by alliance, ceteris paribus.*

C. Hypotheses Regarding the Characteristics of Knowledge

H_E^1: *The more **tacit** the relevant knowledge is, the more likely the problem solving will be organised in-house rather than by outsourcing, ceteris paribus.*

H_E^2: *The more **tacit** the relevant knowledge is, the more likely the problem solving will be organized in-house rather than by alliance, ceteris paribus.*

H_F^1: *The more **socially distributed** the relevant knowledge is, the more likely the problem solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_F^2: *The more **socially distributed** the relevant knowledge is, the more likely that the problem solving will be organized in-house rather than by alliance, ceteris paribus.*

C. Hypotheses Regarding TCE Variables (Transactional Characteristics)

H_G^1: *The more **specific** the relevant **physical assets** are (i.e., those required to support the problem-solving), the more likely the problem-solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_G^2: *The more **specific** the relevant **physical assets** are (i.e., those required to support the problem-solving), the more likely the problem-solving will be organized in-house rather than by alliance, ceteris paribus.*

H_H^1: *The more **specific** the relevant **human assets** are (i.e., those required to support the problem-solving), the more likely the problem-solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_H^2: *The more **specific** the relevant **human assets** are (i.e., those required to support the problem-solving), the more likely the problem-solving will be organized in-house rather than by alliance, ceteris paribus.*

H_I^1: *The higher the **demand uncertainty** of the relevant product is, the more likely the problem-solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_I^2: *The higher the **demand uncertainty** of the relevant product is, the more likely the problem-solving will be organized in-house rather than by alliance, ceteris paribus.*

H_J^1: *The higher the **appropriability** the relevant knowledge is, the more likely the problem-solving will be organized in-house rather than by outsourcing, ceteris paribus.*

H_J^2 *The higher the **appropriability** the relevant knowledge is, the more likely the problem-solving will be organized in-house rather than by alliance, ceteris paribus.*

When the two forms of alliance are further differentiated, it has been identified in the literature that the effects of the following variables are of particular interests[30].

H_B^3: *The higher the **complexity** of the problem-solving is, the more likely that an equity-based alliance will be chosen over a contract-based alliance to organize the problem-solving, ceteris paribus.*

H_F^3: *The more **socially distributed** the relevant knowledge is, the more likely that an equity-based alliance will be chosen over a contract-based alliance to organize the problem-solving, ceteris paribus.*

H_J^3: *The higher the **appropriability** of relevant knowledge is, the more likely that an equity-based alliance will be chosen over a contract-based alliance to organize the problem-solving, ceteris paribus.*

Having listed the hypotheses, we would now move on to the sections of econometric analyses.

6.3 Binomial Probit Analyses of the Organizational Choices

[30] Given the small sample size, we are not going to test these hypotheses directly, but at least we can examine whether the change of theses variables would have different impacts on the choices of the two types of alliance.

In the section, the organizational choices are treated as a series of binary choices and the binomial probit regression techniques are used to identify the determinants of the choice in each circumstance.

6.3.1 A Note on the Probit Model

A. Binary Choice and the Probit Model

In economics research, many variables of interest take a binary form, which are usually denoted by 0 and 1 as a matter of convenience. Such variables are called dummy or dichotomous variables.

A Binary response model directly describes the response probabilities $P(y_i = 1)$ of the dichotomous dependent variable y_i.

Suppose y_i ($i = 1,...,N$) are N independently distributed observations of the dichotomous dependent variable y_i, and x_i' is a vector of explanatory variables including a constant. The probability that the dependent variable takes value 1 can be written as:

$$P(y_i = 1 \mid x_i) = F(z_i) = F(x_i'\beta)$$

where β is a column vector of parameters and

$$z_i = x_i'\beta$$

is a single linear index. The transformation function F maps z_i into [0,1]. It satisfies in general

$$F(-\infty) = \lim_{x_i'\beta \to -\infty} P(y_i = 1 \mid x_i) = 0,$$

$$F(+\infty) = \lim_{x_i'\beta \to +\infty} P(y_i = 1 \mid x_i) = 1,$$

$$\text{and, } \partial F(z) / \partial z > 0$$

The ***probit model*** assumes that the transformation function F is the cumulative distribution function (cdf) of the standard normal distribution Φ.

The response probabilities could then be written as:

$$P(y_i = 1 | x_i) = \Phi(x_i'\beta) = \int_{-\infty}^{x_i'\beta} \phi(t)dt = \int_{-\infty}^{x_i'\beta} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2} dt$$

where $\phi(\cdot)$ is the probability density function (pdf) of the standard normal distribution.

B. The Latent Variable Model

There is an alternative interpretation that give rise to the ***probit model***, and such interpretation is particular relevant in the current context.

Consider a latent variable which is not observed directly but it is linearly dependent on x_i

$$y_i^* = x_i'\beta + \varepsilon_i$$

Although y_i^* is not observable, the choice y_i could be observed, and the decision rule for the choice is given as follows: an individual choose $y_i = 1$ if the latent variable y_i^* is positive and 0 otherwise, hence the observed variable is

$$y_i = \begin{cases} 1 & if \quad y_i^* > 0 \\ 0 & if \quad y_i^* \le 0 \end{cases}$$

Further assume that (1) each individual observation (x_i, y_i) are independently distributed; (2) the explanatory variables are exogenous; and (3) the error term[31] is normally distributed and homoskedastsic, i.e., $\varepsilon_i | x_i \sim N(0, \sigma^2)$

The probability that individual chooses $y_i = 1$ can be derived from the latent variable and the decision rule.

$$\begin{aligned} P(y_i = 1 | x_i) &= P(y_i^* > 0 | x_i) \\ &= P(x_i'\beta + \varepsilon_i > 0 | x_i) = P(\varepsilon_i > -x_i'\beta | x_i) \\ &= 1 - F(-x_i'\beta) = F(x_i'\beta) \end{aligned} \tag{6.1}$$

[31] The logit model arises when the error term is assumed to have a standard logistic distribution with variance $\pi^2/3$.

as it has been assumed that $\varepsilon_i \mid x_i \sim N(0,\sigma^2)$, F, the he cumulative distribution of ε_i, is symmetric about zero[32]. (6.1) can be further rewritten as:

$$\begin{aligned} P(y_i = 1 \mid x_i) &= 1 - F(-x_i'\beta) = F(x_i'\beta) \\ &= \Phi\left(\frac{x_i'\beta}{\sigma}\right) \end{aligned} \tag{6.2}$$

The probit model arises when $\sigma^2 = 1$, i.e., when $\sigma^2 = 1$,

$$P(y_i = 1 \mid x_i) = F(x_i'\beta) = \Phi\left(x_i'\beta\right) \tag{6.3}$$

Two aspects of this construction deserve some discussion (W. H. Greene, 2008: p. 776).

(1) The assumption of known variance of ε_i (i.e., $\sigma^2 = 1$) is an innocent normalization (given that ε_i has been assumed to be normally distributed). If the variance of ε_i were scaled by an unrestricted parameter $\sigma^2, (\sigma > 0)$, the latent variable will be then be $y_i^* = x_i'\beta + \sigma\varepsilon_i$. However, $(y_i^*/\sigma) = x_i'(\beta/\sigma) + \varepsilon_i$ is still the same model with the same set of data. The observed data will remain unchanged, since the value of the observed choice y_i is determined only by the sign of the latent variable $y_i{*}$ but not its scale. In short, there is not sufficient information in the data such that β and σ can be estimated separately, only the ratio β / σ can be estimated.

(2) The assumption of zero as the threshold is equally innocent if the model contains a constant term. If a were instead supposed to be the non-zero threshold ($a \neq 0$), and α be an unknown constant term. Let x_i' and β, for the present, contain the rest of the index but do not include the constant term. The probability that individual chooses $y_i = 1$ could now be written as:

$$\begin{aligned} P(y_i = 1 \mid x_i) &= P(y_i^* > a \mid x_i) \\ &= P(\alpha + x_i'\beta + \varepsilon_i > a \mid x_i) \\ &= P[(\alpha - a) + x_i'\beta + \varepsilon_i > 0 \mid x_i] \end{aligned} \tag{6.4}$$

[32] For logit model, F is also symmetric about 0.

Because α is an unknown constant term, the difference $(\alpha - a)$ remains an unknown parameter. The end result is that as long as the model contains a constant term, the choice of zero as threshold is a normalization with no significance as this will just affect the constant term.

With the two normalizations and as the error term is assumed to be standard normally distributed and therefore symmetric, we have from (6.1)

$$P(y_i = 1 \mid x_i) = P(y_i^* > 0 \mid x_i) = 1 - F(-x_i'\beta) = F(x_i'\beta) = \Phi(x_i'\beta) \qquad (6.5)$$

C. The Probit Model in the Current Context: A Random Utility Approach

The latent variable y_i^* can be interpreted as the utility difference between choosing y_i = 1 and 0. This is in fact a variant of the ***random utility model*** (Ben-Akiva & Lerman, 1985; Cameron & Trivedi, 2005).

In the current context, we assume that a firm chooses among a set of different organizational modes to minimize the expected costs of governing the productive activities over the duration of the activities (Masten, Meehan, & Snyder, 1991). If we let M^* signify the organizational mode chosen, a representative model of the choice between two modes—say, internal organization (M^i) and market exchange (M^m)—can can expressed as:

$$M^* = \begin{cases} M^m, & if\ C^m < C^i \\ M^i, & if\ C^m \geq C^i \end{cases} \qquad (6.6)$$

where C^i and C^m represent the costs of organizing the activities under these two modes respectively.

However, such costs, by their nature, are difficult to measure and quantify directly. In addition, attempts to compare the costs of organization must confront a basic selection problem—organization costs cannot be directly observed for the mode that is not chosen. As a result, the incidence of organizational costs is then related to a set of observable characteristics of the activities/transaction being organized, and the prediction of organizational mode is based on these observed features.

Suppose the true costs of organization are

$$C^i = x'a + e, \qquad (6.7)$$

$$C^m = x'\beta + u, \qquad (6.8)$$

where x' is a vector of attributes presumed to influence the organization costs, α and β are coefficient vectors, and e and u are supposed to be independently and normally distributed mean-zero random variables. Substituting (6.5) and (6.6) into Equation (6.4), the probability of observing internal organization M^i being chosen becomes:

$$\mathrm{P}(C^i < C^m) = \mathrm{P}(e - u < x'(\beta - \alpha)) \qquad (6.9)$$

As e and u are supposed to be mean-zero normally distributed random variables, the difference between these two normally distributed variables $e-u$ is also normally distributed. As we have shown above, the probit model can be derived from (6.7). Hypotheses regarding organization mode can then be based on the signs and relative magnitudes of the coefficients α and β, rather than on the costs C^i and C^m.

6.3.2 Results and Analysis of the Binomial Probit Estimations

Given the polychotomous nature of the dependent variable (i.e. the organizational choice is to be made from the four alternatives of in-house, the equity-based alliance, the contract-based alliance and market exchange), a multinomial model would be the ideal choice. However, for the following *two* reasons, we believe it is adequate to begin with a binary choice model using the probit regression technique[33].

Firstly, as has been indicated by various authors, the choices between in-house and alliance may entail a series of totally different issues from the choice between alliance and market, or the choice between in-house and market. Therefore, it is justifiable to treat the polychotomous organizational choice as a series of binary choices, which enable the separate identification of the effects of the explanatory variables in each setting. Some previous empirical studies have adopted a similar

[33] The alternative to the probit model is the logit model. In the probit model, the underlying probability distribution is assumed to be a normal distribution, while in the logit model, the logistic distribution is assumed instead. The logistic distribution is similar to the normal distribution except in the tails, therefore, the estimation results are not sensitive to the choice between these two models, unless the number of observations are large, or if the data are concentrated in the tails (Amemiya, 1981; Maddala, 1983). In practice, if the above conditions are not applicable, the choice between probit and logit is usually arbitrary. They would give highly similar results, except that the parameters of these two models are scaled differently. Multiplying the parameters in the probit model by 1.6 are approximately the same as the logit estimates (Amemiya, 1981; Greene, 1999).
In our case, the "unless" conditions do not apply. A tentative estimation using both probit and logit model also reveals that there are no significant differences between the results.

approach (Lopez-Bayon & Gonzalez-Diaz, 2010; Rosiello, 2007; John P. Walsh & Jung, 2011).

Secondly, a big proportion of the empirical literature deal with binary choice of organizational modes—most often[34] in the setting of "make or buy"[35] and typically using the binomial probit[36] or logit technique to pin down the determinants that shape the decision. Adopting the same approach makes *easier* a straightforward comparison of our results with those of previous similar studies.

In the following subsections, we will separately estimate a series of binomial probit models to identify the determinants that shape the choice in each circumstance.

A. In-house vs. Alliance

In this subsection, 119 observations are employed to estimate a binomial probit model that tries to identify the factors that shape the choice between in-house and alliance. Table 6-3-1 reports the descriptive statistics of the dependent variables and twelve explanatory variables initially included in the model. Table 6-3-2 presents the correlations of the explanatory variables.

In this model, organizational mode (ORM) is the dependent variable. When in-house is chosen, ORM is set to 1; if alliance is chosen instead, ORM is set to 0. Among all the 119 samples, 61 are organized internally, 58 by alliance.

As shown in Table 6-3-1，the means of most of the explanatory variables range between 2.4 and 3.6, with EKB, HAS and PAS being the exceptions. The mean of EKB is highest ($\overline{EKB} = 3.723$) among all the 12 explanatory variables, suggesting that a firm would not take up a R&D project internally or by alliance unless it has sufficient knowledge in relevant fields. While the means of the two asset specificity variables are the lowest among all the explanatory variables ($\overline{HAS} = 1.437$,

[34] Other settings include the choice of different forms of alliances, e.g., contract-based alliance vs. Equity-based alliance (Sampson, 2004; Colombo, 2003; Heiman & Nickerson, 2002, 2004); different forms of contracts, e.g., indefinite contract duration vs. definite contract duration (for reviews of empirical literature on contract choice and contract design, see Masten 1999 and Masten & Saussier, 2002); or different entry modes, e.g., greenfield vs. acquisition (Hennart & Park, 1993; Hennart Reddy, 1997; Harzing, 2002; for a review of this topic, see Slangen & Hennert, 2007), wholly-owned subsidiary vs. joint venture (Gatignon & Anderson, 1988; Hennart, 1991).

[35] For a review of the empirical literature on the make-or-buy decision, see Klein (2005).

[36] One minor (and accidental) reason that a binomial probit model rather than logit is used in this research is that the few paradigmatic and most-cited empirical papers (Monteverde and Teece, 1982; Masten, 1984; Masten, Meehan & Snyder, 1991) on this theme adopt a probit model.

$\overline{PAS} = 2.008$), reminding us that the fact that R&D activities do not generally involve highly specific asset.

Moreover, if we group all the 119 samples by their organization modes, it is interesting to note that among the 12 explanatory variables, EKB shows up with the highest inter-group mean value difference[37]. This could be seen as an initial sign that the value of EKB differs systematically under the two organization modes. In other words, samples organized by these two modes differ systematically in terms of their existing knowledge base.

Correlation between explanatory variable is also a matter of concern. Fortunately, in the 119 samples, there is no worrying sign of correlation amongst the 12 explanatory variables (see Table 6-3-2). What is worth mentioning is that there are slight correlations between PS, COM and DEC. Specifically, the three correlation coefficients are 0.437 (PS and COM), 0.639 (PS and DEC), and 0.622 (COM and DEC) respectively. Given that the three variables are all trying to capture some aspect of the same phenomena—the complexity of the problem under consideration—this is far from being a surprise. Rather, the slight correlations encourage us to further differentiate and disentangle the effects of complexity from these three dimensions.

[37] The mean of EKB for samples grouped under in-house is 4.049, whereas the mean for those grouped under alliance is 3.379, making the absolute value of inter-group mean difference 0.67. For all other explanatory variables, the comparable figures are less less than 0.5.

Table 6- 3- 1: Descriptive Statistics for All Variables (In-house vs. Alliance)

Variable Code	Full Name	Mean (S.D.) Entire samples	Mean (S.D.) In-house	Mean (S.D.) Alliance	Min	Max
Dependent Variable (1=In-house; 0=Alliance)		**Num. of Obs.=119**				
ORM	Organization Mode	0.513 (0.502)			0	1
Independent Variables						
PS	Problem Structure	2.748 (0.815)	2.705 (0.803)	2.793 (0.833)	1	4
COM	Complexity	3.513 (0.746)	3.377 (0.778)	3.655 (0.690)	2	5
DEC	Decomposability	2.529 (0.779)	2.508 (0.744)	2.552 (0.820)	1	5
EKB	Existing Knowledge Base	3.723 (0.758)	4.049 (0.644)	3.379 (0.721)	2	5
COD	Codifiability	2.840 (0.833)	2.770 (0.864)	2.914 (0.801)	1	5
TEA	Teachability	2.630 (0.735)	2.574 (0.741)	2.690 (0.730)	1	4
SDK	Social Distribution of Knowledge	3.143 (0.985)	3.377 (0.916)	2.897 (1.003)	1	5
DU	Demand Uncertainty	2.420 (0.839)	2.410 (0.761)	2.431 (0.920)	1	5
HAS	Human Asset Specificity	1.437 (0.646)	1.443 (0.620)	1.431 (0.678)	1	4
PAS	Physical Asset Specificity	2.008 (0.776)	2.049 (0.784)	1.966 (0.772)	1	4
AP1	Appropriability1	3.059 (0.932)	3.115 (0.877)	3.000 (0.991)	1	5
AP2	Appropriability2	3.185 (0.676)	3.262 (0.705)	3.103 (0.640)	2	5

Table 6- 3- 2: Correlations (In-house VS. Alliance)

			PS	COM	DEC	EKB	COD	TEA	SDK	DU	HAS	PAS	AP1	AP2
1	**Problem Structure**	PS	1											
2	**Complexity**	COM	0.437	1										
3	**Decomposability**	DEC	0.639	0.622	1									
4	**Existing Knowledge Base**	EKB	-0.320	-0.316	-0.424	1								
5	**Codifiability**	COD	0.277	0.446	0.392	-0.393	1							
6	**Teachability**	TEA	0.423	0.302	0.345	-0.170	0.373	1						
7	**Socially Distribution of Knowledge**	SDK	-0.008	-0.158	-0.044	0.167	0.049	-0.067	1					
8	**Demand Uncertainty**	DU	0.330	0.168	0.344	-0.202	-0.012	0.062	-0.063	1				
9	**Human Asset Specificity**	HAS	-0.111	0.147	0.025	-0.166	0.288	0.093	-0.112	0.018	1			
10	**Physical Asset Specificity**	PAS	0.070	0.256	0.371	-0.140	0.343	0.154	0.043	0.099	0.348	1		
11	**Appropriablility1**	AP1	-0.482	-0.506	-0.475	0.335	-0.326	-0.364	0.129	-0.227	-0.198	-0.177	1	
12	**Appropriablility2**	AP2	-0.115	-0.273	-0.139	0.117	-0.158	-0.066	-0.015	-0.004	0.027	-0.132	0.157	1

In model 1A, we include all 12 explanatory variables for estimation. The results are shown in Table 6-3-3. In model 1A, the coefficients of four of the transaction cost variables[38], namely DU, HAS, PAS, AP2, carry a "right" sign as it is predicted by TCE, but none of them are significant. This is a somewhat surprising result given that there have been a vast body of empirical literature in this field, which, as the whole, is broadly corroborative of the transaction cost theory. Specifically, in most of the empirical studies, TCE variables such as asset specificity (P. Klein, 2005; Shelanski & Klein, 1995) and appropriability (D. C. Mowery, J. E. Oxley, & B. Silverman, 1996b; Oxley, 1997, 1999) are found to be significant, which add to the cumulative evidence in support of TCE, and ultimately make it a "an empirical success story" (Williamson, 1996a: p. 55). However, on second thought, the result is not that unexpected. As indicated by Kay (1997), most of these empirical studies focus narrowly on the manufacturing (production) activities, whereas other types of productive activities such as marketing, distribution and R&D, which are just as important for a modern multifunctional and multidivisional firm, are relatively ignored. As a consequence, asset specificity explanation for the boundary determination of the firm is far less convincing outside the manufacturing activities. This drawback is most evident in case of the corporate R&D, since both the input and output of R&D[39], are usually characterized by low degree of asset specificity in the sense that they are generally non-specific to use or user. Given the focus of this research, which is exactly the organization of R&D activities, it is not so much of a surprise to observe that the coefficients for both human asset specificity and physical asset specificity are insignificant. Moreover, in this research, we have confined the scope of our data collection to the Chinese consumer electronics industry[40]. In terms of its position in the industrial life cycles (Agarwal & Gort, 1996; Gort & Klepper, 1982; Klepper, 1996, 1997; Porter, 1980), it is widely believed that this industry has entered the mature stage (Dedrick & Kraemer, 2008; Ernst, 2008; Ernst & Naughton, 2008; Shin et al., 2009), which is characterized by, among other things, incremental innovations, standardization of product, and stable demand. Viewed in this way, an insignificant coefficient for DU is also not so unexpected. These being said, we're still a little bit surprised that the two appropriability-related variables AP1 & AP2 all show up with insignificant coefficients, one (AP1) even with the wrong sign, since in

[38] Altogether, five transaction cost variables are included in this mode. Apart from the above four, AP1 is the fifth.

[39] In the case of R&D input, physical asset needed to support R&D activates are mostly *general purpose* facilities, infrastructure and instruments. While R&D output are often in the form of productive knowledge, which, as evidenced by the appropriability hazard that arise from its quasi-public-good nature, are mostly non-relation specific.

[40] The consumer electronics industry is defined to include the following three segments, namely, (1) white goods (home appliance) and brown goods (household audio-video equipment), (2) PC and PC peripherals, and (3) mobile handsets and other personal communication devices.

the existing literatures, appropriability hazard has been shown—both theoretically and empirically—to be a critical concern for the organization of R&D. As the in-house vs. alliance is but one of the whole series of binary choices, we would take a note and move on to see if similar results hold in other circumstances.

Table 6- 3- 3: Probit Estimation Results for Model 1A (In-house vs. Alliance)

Probit regression	Number of obs = 119
Number of cases 'correctly predicted' = 95 (79.8%)	LR chi2(12) = 43.48
Log likelihood = -60.707	Prob > chi2 = 0.0000
Adjusted R^2=0.106	Pseudo R^2[41] = 0.264

	Predicted Sign	*Coefficient (Std. Error)*	*z*	*p-value*	
const		-5.204 (1.968)	-2.644	0.008	***
PS	+(?)	-0.002 (0.251)	-0.010	0.992	
COM	-(?)	-0.592 (0.271)	-2.185	0.029	**
DEC	+	0.638 (0.298)	2.139	0.032	**
EKB	+	1.172 (0.243)	4.819	<0.00001	***
COD	+	0.140 (0.213)	0.655	0.513	
TEA	+	-0.125 (0.208)	-0.598	0.550	
SDK	+	0.236 (0.148)	1.592	0.111	
DU	+	0.104 (0.184)	0.564	0.573	
HAS	+	0.235 (0.238)	0.986	0.324	
PAS	+	0.038 (0.203)	0.186	0.852	
AP1	+	-0.168 (0.179)	-0.940	0.347	
AP2	+	0.118 (0.206)	0.575	0.565	

*** p<0.01; ** p<0.05; * p<0.1

[41] In this paper, when a “pseudo R^2” is reported, it is a McFadden's pseudo R^2. C.f. footnote 50.

Among the seven knowledge-based variables[42], five carry the "right" signs as predicted by theory, three (COM, DEC, and EKB) of them turn out to be significant. Overall, among the 119 observations, model 1A correctly predicts the organizational modes for 95 cases (see Table 6-3-4), yielding a "hit rate" of 79.8 %—a level significantly higher than random predictions (50%), or if all observations were assigned to the most frequently observed structure (51.2%).

Table 6- 3- 4: Classification Table (Model 1A)

		Predicted		*Percentage Correct*
		0	1	
Actual	0	43	15	74.1
	1	9	52	85.2
Overall Percentage				79.8

Following a model selection procedure of sequential elimination using two-sided p-value (alpha = 0.10)[43], 8 variables are dropped. As a result, we reach model 1B in which four variables are included.

The selection of model specification could be justified by testing jointly for the omission of all the 8 variables. The null hypothesis being that,

H_0: *The regression parameters are all zero for the variables of PS, DU, HAS, PAS, COD, TEA, AP1, and AP2.*

And the likelihood ratio test comes up with a Chi2(8)=4.44 and p-value=0.815, suggesting that the null hypothesis could be accepted and all of the parameters for variables PS, DU, HAS, PAS, COD, TEA, AP1, and AP2 could be safely assumed to be zero and be dropped from regression.

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[42] The seven knowledge-based variables are PS, COM, DEC, EKB, COD, TEA, and SDK.

[43] In statistics, a result is said to be "statistically significant" if it is unlikely to have occurred by chance, which is defined by a pre-set threshold probability, or "significance level". The significance level is denoted by α (lowercase alpha) and is known as alpha level. P-value should be understood in the context of of hypothesis testing. Specifically, the p-value is the probability of observing a value for the test statistic that is at least as extreme as the value that was actually observed, assuming that the null hypothesis is true (Cramer & Howitt, 2004).
Put differently, alpha level sets the standard for how extreme the data must be if we are going to reject the null hypothesis, whereas the p-value indicated how extreme the data really are. We then compare the p-value with the alpha level (therefore it is also known as critical p-value) to determine whether the observed data are significantly different form the null hypothesis statistically.
If the p-value is less or equal to the alpha level, we reject the null hypothesis (since either the null hypothesis is false or an unusual event has occurred) and the result is said to be statistically significant. On the contrary, if the p-value is greater than alpha level, we say we fail to reject the null hypothesis.

We then estimate the new model with the four retained variables. The results are shown in Table 6-3-5 In the new model (1B), the coefficients for all the four variables are significant—for DEC and EKB, significant at the 1% level; for COM, significant at the 5% level, and for SDK, significant at the 10% level. While in model 1A, only 3 variables are with a significant coefficient and only the coefficient for EKB is significant at the 1% level. It is also worth noting that even with 8 variables being dropped, the predicative power of the new model does not suffer much, as the "hit rate" of model 1B is only a 3.3% lower than model 1A (down from 79.8% to 76.5%, see Table 6-3-6), and the pseudo R^2[44] of the model 1B drop by a mere 0.027 (pseudo R^2 for model 1A is 0.264, whereas for model 1B is 0.237).

[44] C.f. footnote 50.

Table 6- 3- 5: Probit Estimation Results for Model 1B (In-house vs. Alliance)

Probit regression	Number of obs = 119
Number of cases 'correctly predicted' = 91 (76.5%)	LR chi2(4) = 39.06
Log likelihood = -62.915	Prob > chi2 = 0.0000
Adjusted R-squared= 0.176	Pseudo R^2 = 0.237

	Predicted Sign	*Coefficient (Std. Error)*	*z*	*p-value*	
const		-4.707 (1.318)	-3.572	0.000	***
COM	-(?)	-0.469 (0.237)	-1.980	0.048	**
DEC	+	0.668 (0.240)	2.791	0.005	***
EKB	+	1.057 (0.224)	4.709	0.000	***
SDK	+	0.244 (0.141)	1.727	0.084	*

*** p<0.01; ** p<0.05; * p<0.1

Table 6- 3- 6: Classification Table (Model 1B)

		Predicted 0	*Predicted* 1	*Percentage Correct*
Actual	0	44	14	75.9
	1	14	47	77.0
Overall Percentage				76.5

Marginal Effects

In the probit regression, the coefficients have no direct interpretation because they measure the change in some *unobservable* y* in response to the change in one of the explanatory variables. A more useful measure is the so-called marginal effects.

Specifically, this measure captures the marginal effects of the explanatory variables on the probability of a specific choice. It can be calculated in the following way:

$$P(y=1)=\Phi(Z)$$

where $Z=\beta_0+\beta_1x_1+...\beta_kx_k$, and Φ is the cumulative distribution function (cdf) of the standard normal distribution.

The marginal effect for i^{th} explanatory variable can be written as:

$$\frac{\partial P(y=1)}{\partial x_i} = \frac{dP(y=1)}{dZ}\frac{\partial Z}{\partial x_i} = \phi(Z)\beta_i = \left(\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}Z^2}\right)\beta_i \quad (6.10)$$

As $\left(\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}Z^2}\right) > 0$, the sign of the marginal effect for i^{th} explanatory variable is always the same as that of β_i —its coefficient in the probit regression. It should also be noted that the marginal effect not only depends on the coefficient β_i, it also varies with Z. That is to say, the marginal effect depends also on the characteristics of the observation, and each individual observation has a different marginal effect. A common practice for evaluating the representative "marginal effect" is to calculate the value by using the Z given by the sample means of all the explanatory variables, i.e., using $x_i = \overline{x_i}$ when calculating Z.

Table 6-3-8 presents the marginal effect of each of four variables calculated in this way. At sample means of the explanatory variables, the marginal effect of EKB is both strongest and most significant among all the variables: a one-point increase in EKB adds to the probability of choosing in-house by 42.1%. The marginal effect of DEC is also significant at the 1% level, but with a smaller magnitude: a one-point increase in DEC would yield a 26.6% higher probability of choosing in-house. By contrast, the marginal effect of COM is to the opposite direction: a one-point increase in COM decreases the probability of choosing in-house by 18.7%, and the effect is significant at the 5% level. The marginal effect of SDK is even smaller, a one-point increase in SDK adds to the probability of choosing in-house only by 9.7 %, and this effect is only marginally significant (at the 10% level).

Table 6- 3- 7: Marginal effects at Sample Means (Model 1B)

$y = Pr(\text{ORM} = 1 \mid x = \bar{x}) = 0.516$

Variable	dy/dx (Std. Err.)	z	*p-value*	
COM	-0.187 (0.094)	-1.98	0.048	**
DEC	0.266 (0.095)	2.79	0.005	***
EKB	0.421 (0.090)	4.71	0.000	***
SDK	0.097 (0.056)	1.73	0.084	*

*** p<0.01, ** p<0.05, * p<0.1

However, as the four explanatory variables are all discrete ordered variables taking the integer value from 1 to 5, a possibly more appropriate way to demonstrate the marginal effects is to present them on a point-by-point incremental basis(see Table 6-3-8, Figure 6-3-1 and Figure 6-3-2).

Table 6- 3- 8: Marginal Effects of the Explanatory Variables on a Point-By-Point Incremental Basis † (Model 1B)

	1→2	2→3	3→4	4→5
COM	-0.115*	-0.163	-0.185	-0.170
DEC	0.214	0.262	0.208	0.108
EKB	0.035*	0.198	0.395	0.287
SDK	0.091	0.096	0.096	0.091

† When calculating the marginal effects of a variable, other variables are held constant at their sample means.

* The minimum value of COM and EKB in the samples is 2. None of the observation takes the value of 1 for COM or EKB.

Figure 6- 3- 1: The Effects of the Point-by-Point Increase of Each Explanatory Variables on Pr(y=1) (Model 1B)

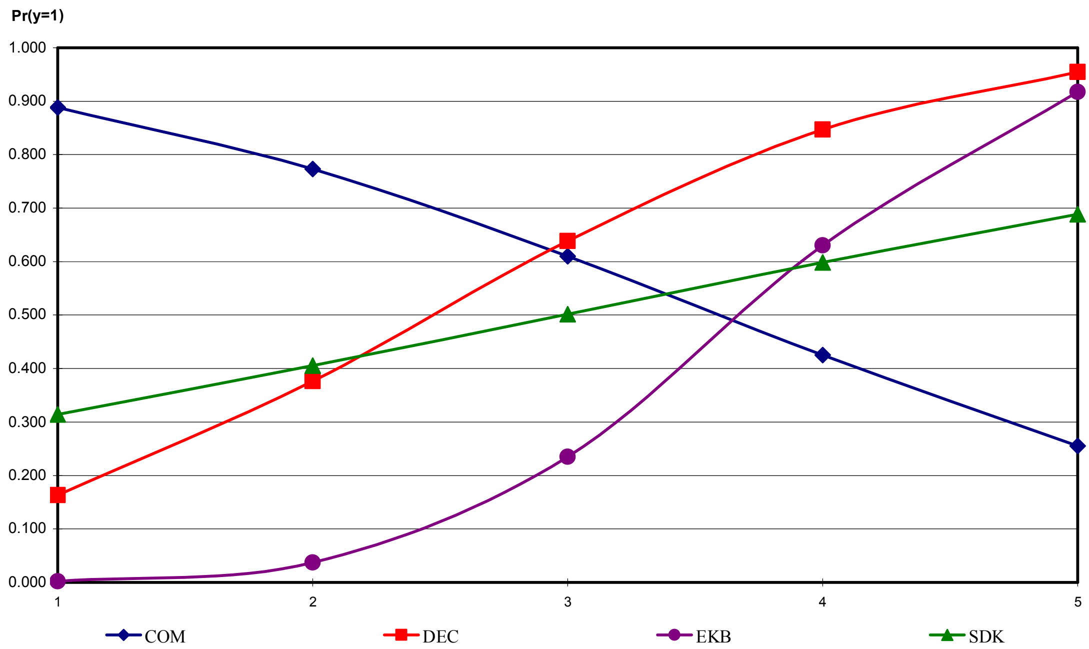
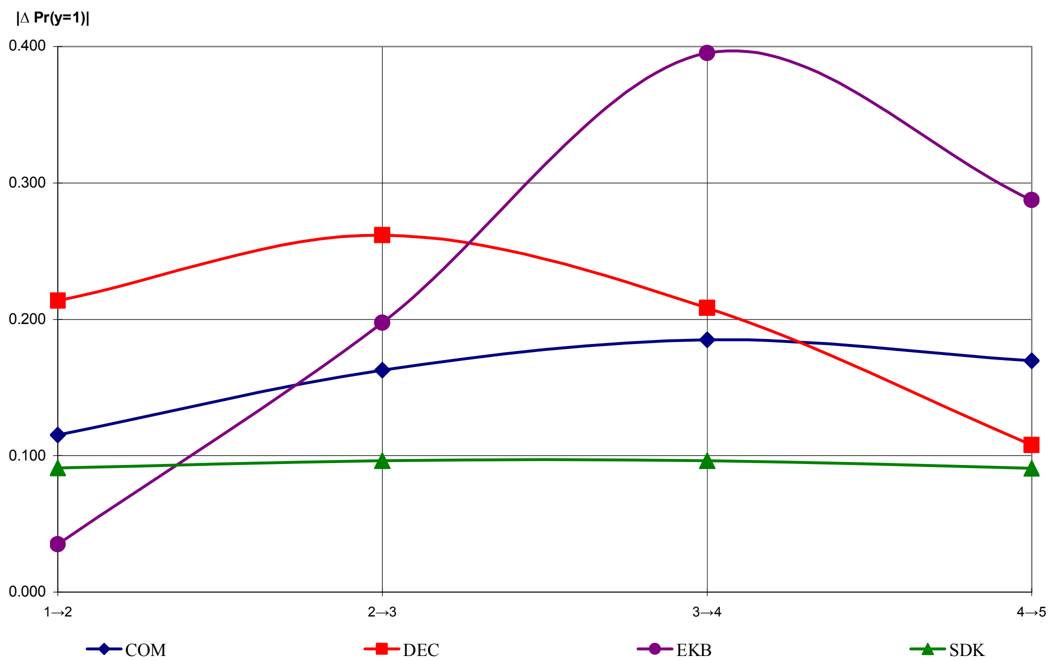


Figure 6- 3- 2: Marginal Effects of the Explanatory Variables on a Point-By-Point Incremental Basis*(Model 1B)



* For comparison, marginal effects are shown in absolute magnitude irrespective of their sign. It should be noted that the marginal effect of COM is negative.

As shown in Figure 6-3-1, 6-3-2 and Table 6-3-8, for some variables, such as SDK and COM, the marginal effects are rather uniform and linear. In the case of SDK, the marginal effects throughout the range of its value are around 10%, whereas for COM, the figures fluctuate narrowly around 16%. By contrast, the marginal effects of the other two variables *vary more drastically*. For EKB, each one-point increase adds to the predicted probability of choosing in-house by at least 19%, and the effect is so strong when EKB increases from 3 to 4 that it leads to a 40% leap in the predicted probability of choosing in-house. While for DEC, the marginal effect is strongest when its value changes form 2 to 3, which adds to the probability of choosing in-house by 26%. After that, the magnitude of its marginal effect diminishes steadily. For the last one-point increase in DEC, the marginal effect is only slightly over 10%.

Summary and Discussion

In this subsection, we estimate the determinants that shape the organizational choice between in-house and alliance. As it has been noted, in model 1A, none of the five transaction cost variables is statistically significant—put differently, the coefficients for all these transaction cost variables are not statistically different from zero. This result is somewhat unexpected. As the choice between in-house and alliance is but one of the many binary choices in our analysis, we would take note of this and move on to see if similar results hold in other context.

On the other hand, the estimation results tend to support most of the knowledge-based hypotheses. Among all the variables, the coefficient for EKB is most significant (at the level of 1%, model 1B). Its positive sign suggests that a higher EKB favours the choice of internal organization. This result is consistent with the knowledge-based prediction (Argyres, 1996; Jacobides & Hitt, 2005; Poppo & Zenger, 1998). The underlying logic is straightforward[45]—as a firm has increasingly more complete knowledge that is required to solve a problem, it is more likely that the R&D project will be organized in-house. On the other hand, if the firm does not have enough knowledge for solving the problem, the firm might have to refer to external knowledge source for finding a solution—forming alliance with other firms (Grant & Baden-Fuller, 2004) is one of such options.

The coefficient of DEC is also significant at the level of 1% (model 1B), and with a positive sign, meaning that a higher DEC value adds to the chance of choosing in-house. This result is also consistent with the prediction of problem-solving

[45] A more general proposition in this line could be found in Jacobides and Hitt (2005). They state that "firms with greater productive capabilities in a stage of production will tend to perform this activity internally, and contract with another firm through the 'market' where they are deficient" (p. 1210).

perceptive (Brusoni, 2005; Brusoni et al., 2007; Dosi, Hobday, & Marengo, 2003; Langlois, 2002; Marengo & Dosi, 2005; Nickerson & Zenger, 2004). Specifically, a higher DEC means the problem is less decomposable. If one is going to find a solution for such problem, it has to be an overall solution; any partial solution is simply impractical. Accordingly, the solution search for such problem needs intensive and extensive coordination. Hierarchy, with all the coordination and communication facilities, is thought to be more efficient for solving non-decomposable problem.

COM is the third significant knowledge-based variable. In model 1B, it is estimated to be significant at the level of 5%, but with a ***negative*** sign. That is to say, as the value of COM changes form 1 to 5, the probability that alliance is chosen tends to increase. This result is at odds with the prediction of *some* of the knowledge-based theorists[46], who asserts generally that the more complex the problem is, the more likely the solution search will be organized internally (Heiman & Nickerson, 2002, 2004; Leiblein & Macher, 2009; Leiblein et al., 2009; Macher, 2006; Macher & Boerner, 2011; Nickerson & Zenger, 2004). However, to the current author, the

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[46] C.f discussion on section 7.1.1.
To be more exact, the prediction of knowledge-based view is rather ambiguous in this regard.
In the face of the make-or-buy decision, KBV predicts that in-house is more effective for solving complex problems, while market mode of organization realizes performance advantages when the problem is simple (Nickerson & Zenger, 2004; Macher, 2006; Macher & Boerner, 2011). When the choices is among various forms of alliance, KBV predicts that more hierarchical forms of alliance (e.g. joint venture) are more likely to be chosen when problem-solving complexity is higher (Heiman & Nickerson 2004), or when the need for design-production coordination is greater (Leiblein, Macher, & Ziedonis, 2009).
If the organizational choice is presented as a polychotomous rather than a binary choice, it is generally assumed that alliances are sort of hybrid modes lying somewhere in between internal organization (hierarchy) and arm's-length market contract. Accordingly, it is argued that compared with alliances, internal organization is more efficient in dealing with highly complex problems, while alliances are more appropriate for solving moderately complex problems (Leiblein & Macher, 2009).
Nevertheless, we note that some other knowledge-based proponents (Coombs & Metcalfe, 2000; Grant & Baden-Fuller, 2004) predict to the contrary. For example, Coombs and Metclafe's (2000) argue that in a world of increasing technological complexity, it is less likely that the knowledge/capabilities required certain fundamental innovations are readily located within a single firm. Rather, they are often distributed/dispersed across a range of firms and other knowledge generating institutions. Such innovations require coordination of existing capabilities and, possibly, the generation of new capabilities through novel combination. Accordingly, the firms refer more often to the range of cooperative arrangements for accomplishing such 'distributed innovation processes'.
To rephrase, the essence of their argument is that the firms rely on various collaborative arrangements to access capabilities/knowledge which they do not posses but nevertheless are required for solving a highly complex problem that internal organization simply isn't able to cope with. It is also worth noting that they define the complexity of a innovation in terms of the following three aspects: (1) technological diversity (i.e., the range of constituent technologies and knowledge bases); (2) systematic complexity (i.e., the need to coordinate between different technological interfaces of the constituent technologies/knowledge); and (3) connectedness (i.e., on the one hand, the interconnections among different scientific disciplines (technological fields) are increasingly more extensive and more intensive; on the other hand, each scientific discipline and technological field tends to be more specialized). Such definition is highly compatible with ours.

result is far from being a surprise. In our understanding, alliances are probably not the "hybrid" modes of organization that lie somewhere between the polar modes of market and hierarchy (Williamson, 1991). Rather, they should be viewed as an independent category of organization mode. In terms of organization costs, they might even be the most expensive category[47]. Unless absolutely necessary, or in other words, unless it could offer some sort of benefits that other organizational modes simply could not deliver, a firm would generally tend to avoid such "hybrid" forms of organization. That being said, we also believe that alliances do offer some unique benefits—predominantly, to get access to complementary knowledge, especially in the face of solving a (non-decomposable) complex problem that goes beyond the existing capabilities/knowledge base of the firm. More specifically, as the problems to be solved become increasingly complex, the firm would certainly come to knowledge/capabilities bottlenecks at some point. Naturally, when solving such complex problems, the firm would have to refer to external sources for accessing complementary knowledge, most possibly by forming alliances with other firms (Coombs & Metcalfe, 2000; Grant & Baden-Fuller, 2004). Summing up, in the context of choosing between in-house and alliances, it is reasonable to argue that the more complex the problem is, the less likely the problem can be solved internally (for lack of complete knowledge); or equivalently, the more likely the problem-solving will be organized by Alliance. We believe the above chains of arguments are consistent with the logic of the knowledge-based view.

Finally, in model 1B, the coefficient of SDK is estimated to be positive and is significant at the level of 10%. This means, the more socially distributed the relevant knowledge is (higher SDK), the more likely internal organization will be chosen to solve the problem. This result is consistent with the prediction of the knowledge-based view (Langlois & Foss, 1999; Marengo, 1995; Tsoukas, 1996). The underlying mechanism is as follows: productive knowledge often emerges and accumulates in the firm-specific context; it is often widely distributed among a group of interacting agents and is not possessed by any single agent. Such knowledge is hard to be dismantled form the social context it emerges, and could therefore only be mobilized in the context of carrying out a multi-person productive task. In short, KBV argues that socially distributed knowledge is better utilized internally.

[47] This is especially ture for equity joint venture.

B. In-house vs. Outsourcing

In this subsection, 84 observations (61 in-house and 23 outsourcing) are used to estimate a series of probit models to pin down the factors that shape the choice between in-house and outsourcing. The descriptive statistics of the all the variables are presented in Table 6-3-9 and the correlation of the explanatory variables are presented in Table 6-3-10.

In this model, the dependent variable (organization mode) is set to 1 when in-house is chosen; if outsourcing is chosen instead, it is set to 0. As shown in table 6-3-9, if we group all the 84 samples by their organization modes, we would find that the inter-group mean value difference for the explanatory variables tend to be greater than the comparable figure in previous case (in-house vs. alliance). Specifically, for four of the variables (PS, COM, DEC and EKB), the absolute magnitude of inter-group mean value difference is greater than 0.5, while in previous case, only EKB meets this criteria. These could be viewed as initial signals that R&D projects organized under these two modes might differ systematically along the above four dimensions[48].

As for the correlations between explanatory variables, we note that there are slight correlations between PS, COM and DEC, with their correlation coefficients being 0.536 (PS and COM), 0.684 (PS and DEC) and 0.674 (COM and DEC) respectively, but the magnitudes of the correlations might not be deemed particularly worrying.

[48] In particular, EKB, whose inter-group mean value difference (1.136) is again greatest among all variables.

Table 6- 3- 9: Descriptive Statistics for All Variables (In-house vs. Outsourcing)

Variable Code	Full Name	Mean (S.D.)			Min	Max
		Entire Samples	In-house	Outsourcing		
Dependent Variable (1=In-house; 0=Outsourcing)			**Num. of Obs.=84**			
ORM	Organization Mode	0. 726 (0.449)			0	1
Independent Variables						
PS	Problem Structure	2.560 (0.812)	2.705 (0.803)	2.174 (0.717)	1	4
COM	Complexity	3.238 (0.770)	3.377 (0.778)	2.870 (0.626)	2	5
DEC	Decomposability	2.357 (0.786)	2.508 (0.744)	1.957 (0.767)	1	5
EKB	Existing Knowledge Base	3.738 (0.920)	4.049 (0.644)	2.913 (1.041)	2	5
COD	Codifiability	2.738 (0.838)	2.770 (0.864)	2.652 (0.775)	1	5
TEA	Teachability	2.524 (0.799)	2.574 (0.741)	2.391 (0.941)	1	4
SDK	Social Distribution of Knowledge	3.476 (1.000)	3.377 (0.916)	3.739 (1.176)	1	5
DU	Demand Uncertainty	2.393 (0.807)	2.410 (0.761)	2.348 (0.935)	1	5
HAS	Human Asset Specificity	1.405 (0.604)	1.443 (0.620)	1.304 (0.559)	1	4
PAS	Physical Asset Specificity	1.917 (0.748)	2.049 (0.784)	1.565 (0.507)	1	4
AP1	Appropriability1	3.143 (0.880)	3.115 (0.877)	3.217 (0.902)	1	5
AP2	Appropriability2	3.179 (0.679)	3.262 (0.705)	2.957 (0.562)	2	5
AVECOM	AVECOM= (PS+COM+DEC)/3	2.719 (0.685)	2.863 (0.665)	2.333 (0.594)	1.33	4

Table 6- 3- 10: Correlation (In-house vs. Outsource)

			PS	COM	DEC	EKB	COD	TEA	SDK	DU	HAS	PAS	AP1	AP2	AVECOM
1	**Problem Structure**	PS	1												
2	**Complexity**	COM	0.536	1											
3	**Decomposability**	DEC	0.684	0.674	1										
4	**Existing Knowledge Base**	EKB	-0.14	-0.064	-0.202	1									
5	**Codifiability**	COD	0.36	0.453	0.382	-0.246	1								
6	**Teachability**	TEA	0.583	0.324	0.447	-0.221	0.37	1							
7	**Social Distribution of Knowledge**	SDK	0.009	-0.102	-0.02	-0.125	0.021	-0.09	1						
8	**Demand Uncertainty**	DU	0.304	0.139	0.308	-0.152	0.065	0.144	-0.041	1					
9	**Human Asset Specificity**	HAS	0.172	0.257	0.174	-0.089	0.379	0.155	-0.184	0.263	1				
10	**Physical Asset Specificity**	PAS	0.177	0.328	0.42	-0.067	0.253	0.135	0.038	0.095	0.236	1			
11	**Appropriability1**	AP1	-0.434	-0.389	-0.336	0.285	-0.259	-0.348	-0.01	-0.097	-0.246	-0.165	1		
12	**Appropriability2**	AP2	-0.162	-0.312	-0.211	0.23	-0.213	-0.13	-0.091	-0.086	-0.149	-0.255	0.259	1	
13	**AVECOM***	AVECOM	0.857	0.844	0.905	-0.157	0.458	0.522	-0.042	0.29	0.23	0.353	-0.445	-0.261	1

* AVECOM=(PS+COM+DEC)/3

Using the 84 observations, we estimate a probit model to pin down the determinants that shape the choice between in-house and outsourcing.

As a first step, all the 12 explanatory variables are included in the baseline model (model 2A). The estimation results for this model are shown in Table 6-3-11 and Table 6-3-12. In model 2A, the coefficients of 7 variables are estimated with a theoretically consistent sign, 4 of them being significant—of which two are transaction cost variables (PAS and AP2), and the other two knowledge-based variables (EKB, DEC). Among these four significant variables, EKB is significant at the level of 1%, while DEC, PAS and AP2 are significant only at the level of 10%. Overall, of the 84 observations, model 2A correctly predicts the organization modes for 75 cases, which yields a "hit rate" of 89.3%—a figure 17% higher than if all observations were assigned to the most frequently observed structure (72.6%).

As we have noted above, the correlation table indicates that the three measures of complexity—PS, COM and DEC—are somewhat correlated with each other. Although not particularly worrying, there is still a concern over multicollinearity that requires some considerations. We then try different model specifications by including only one of the three variables each time. To be more exact, PS, COM, and DEC are included separately in model 2B, 2C and 2D[49], alongside with the other 9 variables. The estimation results of these three models are presented is table 6-3-13.

The results of the three models share some similarities. Firstly, as in model 2A, in each of the new specifications, EKB, PAS and AP2 all show up with a significant coefficient, and the effect of EKB is always the most significant among all the explanatory variables. Moreover, in each of the new specifications, the coefficient of the complexity-related variable, either it be PS, COM, or DEC, is invariably significant, and at the level of 5%. By contrast, it is interesting to note that when all the three complexity-related variables are included in the same model (model 2A), only DEC comes up with a significant coefficient, and merely at the level of 10%.

[49] To justify each of the three new specifications, we test the following three hypotheses on the basis of model 2A.

To justify model 2B, we test the following restriction sets: 1: $\beta_{COM}=0$ and; 2: $\beta_{DEC}=0$.

The tests statistic is as follow: chi 2 (2) = 4.1728, with p-value = 0.12.

To Justify model 2C, we test test the following restriction sets: 1: $\beta_{PS}=0$ and; 2: $\beta_{DEC}=0$.

The tests statistic is as follow: chi 2 (2) = 4.0510, with p-value = 0.13.

To Justify model 2C, we test test the following restriction sets: 1: $\beta_{PS}=0$ and; 2: $\beta_{COM}=0$.

The tests statistic is as follow: chi 2 (2) = 1.5553, with p-value = 0.46.

Summing up, in each case, the null hypothesis could not be rejected. That means, all the three specifications could be justified from a statistical point of view.

The above results seem to suggest, as the far as the choice of in-house vs. outsourcing is concerned, each of the three complexity-related variables is equally valid in capturing the effects of complexity. By including only one of the three variables each time, the potential multicollinearity problem is avoided, and the level of significance for the complexity-related variable increases accordingly (from 10% to 5%).

On the basis of the above results, we try a fifth model specification. Specifically, a new variable AVECOM—which is defined as the average of the three complexity-related measures—is constructed, the new variable is then used to replace all the three complexity-related variables in the model. Supposedly, the new specification might have a few advantages. In the first place, unlike the practice of including only one of the three complexity-related variables and dropping the other two, no information in the data set would be lost in the new specification, since the information on all the three variables have been included in the new single construct. In addition, under the new specification, the potential problem of multicollinearity between PS, COM and DEC, if any, could be avoided as well.

To justify the construction of the new variable, we test for the equality of the coefficients for the three complexity-related variables in the baseline model. The null hypothesis being that,

H_0: *The regression parameters for the three variables PS, COM and DEC are equal, i.e.,* $\beta_{PS} - \beta_{COM} = 0,\ \beta_{PS} - \beta_{DEC} = 0$.

And the likelihood ratio test comes up with a Chi2 (2)=1.0915 and p-value=0.58, suggesting that the null hypothesis could not be rejected, i.e., it is safe to assume that the parameters for PS, COM and DEC are equal. Accordingly, it is justifiable to merge these three variables into the new one (AVECOM).

The estimation result of the new model (2E) is also included in Table 6-3-13. Again, the result is quite similar to that of the baseline model (model 2A), but this time the new variable AVECOM comes up with a much more significant coefficient (at the level of 1%). Moreover, by the two measures of fit—pseudo R^2 and the “hit rate”—the new model is superior to model 2B, 2C, or 2D[50].

[50] Having said that, we are aware that the power of these two meausres should not be overstated (Hoetker, 2007). In the following discussion, we would focus on pseudo R^2.
A pseudo R^2 is an extension of R^2 to the nonlinear regression models.

In the ordinary linear regression model (LRM), R^2 is a statistic often used as a goodness-of-fit measure. Specifically,

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{N} (y_i - \overline{y})^2}$$

where N is the number of observations in the model, y_i is the *ith* observation of the dependent variable, $\overline{y}$ is the mean of the y, and $\hat{y}_i$ is the predicted value of the ith observation given by the model.

In the linear regression model, R^2 could be interpretated in several ways. To list a few: proportion of explained variance, improvement from null model to fitted model (relative gain), squared correlation between actual and predicted values, a transformation of the F-statistic etc. These different interpretations give rise to the existence of multiple pseudo R^2 measures (Long 1997; Long & Freese, 2006; Cameron & Trivedi, 2005).

McFadden's pseudo R^2 (McFadden, 1974) is perhaps the most popular version of pseudo R2. In Stata, this measure is directly reported as pseudo R^2.

One interpretation of R^2 in the LRM is the level of improvement over the intercept model offered by the full model. McFadden's pseudo R^2 could be understood straightforwardly as its logical analogy in the non-linear models.

Specifically, in LRM, the denominator of the ratio in R^2, i.e., $\sum_{i=1}^{N} (y_i - \overline{y})^2$, can be thought of as the sum of squared errors of the null model—a model predicting the dependent variable without any independent variables, in which each y is predicted to be the mean of the y (without any further information, the mean of the y would be the best guess). The numerator of the ratio in R^2, i.e., $\sum_{i=1}^{N} (y_i - \hat{y}_i)^2$, is the sum of squared errors of the fitted model. This ratio $\sum_{i=1}^{N} (y_i - \hat{y}_i)^2 \big/ \sum_{i=1}^{N} (y_i - \overline{y})^2$, as a whole, is inversely associated with the level to which the fitted model improve upon the prediction of the null model. The smaller this ratio is, the greater the improvement and the higher the R^2.

McFadden's pseudo R^2 is defined in the same spirit, specifically,

$$R^2_{\text{McF}} = 1 - \frac{\ln \hat{L}(M_{Full})}{\ln \hat{L}(M_{Intercept})}$$

where M_{Full} is the model with predictors, $M_{Intercept}$ is the model without predictors (intercept only), and $\hat{L}$ is the estimated likelihood.

As ln() is monotonic, McFadden's pseudo R^2 in fact compares the likelihood of the intercept-only model to the likelihood of the full model (with predictors), and the ratio $\ln \hat{L}(M_{Full}) \big/ \ln \hat{L}(M_{Intercept})$ is inversely associated with the level of improvement from null (intercept-only) model to the full model. To illustrate, in the case of discrete outcomes model, the likelihood falls between 0 and 1, so the log of a likelihood is less than or equal to zero. If a model has a very low likelihood, then the log of the likelihood will have a greater magnitude than the log of a more likely model. Therefore, a small ratio of log likelihoods indicates that the full model is far better than the intercept model. And if comparing two models on the same data, McFadden's Pseudo R^2 would be higher for the model with a greater likelihood.

It is also worth noting that in the case of discrete outcome models, the McFadden's pseudo R^2 can be as low as zero ($M_{Full} = M_{Intercept}$) but can never equal one ($\ln \hat{L}(M_{Full}) \big/ \ln \hat{L}(M_{Intercept}) > 0$).

In a binary choice model,

$$R^2_{\text{McF}} = 1 - \frac{\ln \hat{L}(M_{Full})}{\ln \hat{L}(M_{Intercept})} = 1 - \frac{\sum_i \left[y_i \ln \hat{p}_i + (1 - y_i) \ln(1 - \hat{p}_i) \right]}{N \left[\overline{y} \ln \overline{y} + (1 - \overline{y}) \ln(1 - \overline{y}) \right]}$$

where $\hat{p}_i = F(x_i' \hat{\beta})$ and $\overline{y} = \left(\sum_i y_i \right) \big/ N$.

To sum up, each of the fours specification (2B, 2C, 2D and 2E) exhibits some unique strength (see Table 6-3-14)[51], and all of them make some improvements over the baseline model of 2A. Most noticeably, model 2B excels in terms of the numbers of coefficients bearing a theoretically consistent sign; model 2C comes up with the highest numbers of significant variables; and model 2E performs best in terms of goodness-of-fit, as indicated by its highest pseudo R^2 and "hit rate". However, if a decision regarding the selection of model specification has to be made, model 2E is the choice. Above all, model 2E fits the data best among all the four alternatives. Additionally and more importantly, by combining the three variables into one single construct, model 2E makes better use of the available information in the data set; while in the other three cases, the information on some of the variables are simply disregarded.

Having explained the McFadden's pseudo R^2 at some length, we conclude that the measure is of relatively low power. In the first place, there is no distribution and hence no way of knowing whether one R^2 is significantly different from another R^2. Furthermore, there is no clear interpretation for values other than 0 and 1, nor is there any standard by which to judge if a value is "good" enough. A small pseudo R^2 might make one humble about the model's explanatory ability, but a big pseudo R^2 should not be taken as something necessarily wonderful. Afterall, it is just an expedient guide for fitting models (Long, 1997).

[51] Compared with the other three alternatives (2C, 2D and 2E), model 2B is the least fitting in terms of its pseudo R^2. However, it is interesting to observe that the model is, at the same time, the second best in terms of its "hit rate", outperformed only by model 2E. Additionally, of the 10 variables included in model 2B, 6 come up with the "correct" sign as predicted by the theory, while in the other three models, only 5 variables bear a theoretically-consistent sign. Finally, in model 2B, the coefficients for 4 of the variables are estimated to be significant at the level of 5% or higher, of which 2 are significant at the level of 1% (EKB, PAS); by contrast, in model 2C and 2D, only EKB is significant at the level of 1%, and in model 2E, only three variables are significant at the levl of 5% or higher.

Meanwhile, model 2C and model 2D each enjoys some advantages. To be more specific, in model 2C, one more variable (TEA) comes up with a significant coefficient (in all the other three alternative models, only 4 variables are estmated to be significant at the level of 10% or higher) ; and all the 5 significant variables are estimated to be at the level of 5% or higher. As for model 2C, we note that its pseudo R^2 is higher than that for model 2B and model 2E (but slightly less than that for model 2E), suggesting that this model fit the data somewhat more accurately than the model 2B and 2E.

Table 6- 3- 11: Probit Estimation Results for Model 2A (In-house vs. Outsourcing)

Probit regression	Number of obs = 84
Number of cases 'correctly predicted' = 75 (89.3%)	LR chi2(12) = 66.31
Log likelihood = -16.155	Prob > chi2 = 0.0000
Adjusted R^2=0.409	Pseudo R^2 = 0.672

	Predicted Sign	*Coefficient (Std. Error)*	*z*	*p-value*	
const		-14.828 (4.840)	-3.064	0.002	***
PS	+	0.288 (0.551)	0.522	0.601	
COM	+	0.533 (0.525)	1.015	0.310	
DEC	+	1.524 (0.912)	1.670	0.095	*
EKB	+	2.368 (0.765)	3.096	0.002	***
COD	+	-0.240 (0.499)	-0.482	0.630	
TEA	+	0.505 (0.567)	0.892	0.372	
SDK	+	-0.103 (0.256)	-0.401	0.689	
DU	+	-0.285 (0.403)	-0.708	0.479	
HAS	+	-0.267 (0.538)	-0.496	0.620	
PAS	+	0.942 (0.535)	1.759	0.079	*
AP1	+	-0.578 (0.437)	-1.324	0.186	
AP2	+	0.764 (0.458)	1.669	0.095	*

*** p<0.01; ** p<0.05; * p<0.1

Table 6- 3- 12: Classification Table (Model 2A)

		Predicted 0	*Predicted* 1	*Percentage Correct*
Actual	0	17	6	73.9
	1	3	58	95.1
Overall Percentage				89.3

Table 6- 3- 13: Probit Estimation Results for Various Model Specifications (In-house vs. Outsourcing)

Var Code	Predicted Sign	Model 2A	Model 2B	Model 2C	Model 2D	Model 2E
		Coeff. (S.E.)	Coeff. (S.E.)	Coeff. (S.E.)	Coeff. (S.E.)	Coeff. (S.E.)
const		-14.828*** (4.840)	-10.476*** (3.631)	-12.042*** (3.285)	-13.144*** (4.548)	-13.747*** (4.084)
PS	+	0.288 (0.551)	0.963** (0.437)	——	——	——
COM	+	0.533 (0.525)	——	1.004** (0.433)	——	——
DEC	+	1.524* (0.912)	——	——	1.900** (0.840)	——
AVECOM[52]	+	——	——	——	——	2.000*** (0.739)
EKB	+	2.368*** (0.765)	1.576*** (0.441)	1.662*** (0.431)	2.321*** (0.747)	2.005*** (0.575)
COD	+	-0.240 (0.499)	0.178 (0.351)	-0.113 (0.352)	-0.033 (0.433)	-0.194 (0.410)
TEA	+	0.505 (0.567)	0.175 (0.422)	0.780** (0.397)	0.353 (0.452)	0.467 (0.433)
SDK	+	-0.103 (0.256)	-0.136 (0.227)	-0.078 (0.233)	-0.111 (0.252)	-0.084 (0.248)
DU	+	-0.285 (0.403)	-0.205 (0.339)	-0.047 (0.317)	-0.282 (0.390)	-0.288 (0.383)
HAS	+	-0.267 (0.538)	-0.0433 (0.483)	-0.130 (0.507)	-0.111 (0.540)	-0.240 (0.506)
PAS	+	0.942* (0.535)	1.167*** (0.452)	0.976** (0.420)	0.833* (0.500)	1.066** (0.503)
AP1	+	-0.578 (0.437)	-0.388 (0.342)	-0.468 (0.346)	-0.694 (0.436)	-0.421 (0.373)
AP2	+	0.764* (0.458)	0.730** (0.372)	0.749** (0.380)	0.796* (0.459)	0.722* (0.409)
Pseudo R^2		0.672	0.597	0.603	0.656	0.659
Adjusted R^2		0.409	0.374	0.380	0.433	0.436
Hit rate		89.3%	90.5%	89.3%	89.3%	91.7%

*** $p<0.01$; ** $p<0.05$; * $p<0.1$

[52] The new variable AVECOM is defined as the average of the three complexity-related measures, i.e., AVECOM=(PS+COM+DEC)/3

Table 6- 3- 14: A Comparison of the Strengths of Various Model Specifications (In-house vs. Outsourcing)

		Model 2A	*Model 2B*	*Model 2C*	*Model 2D*	*Model 2E*
Num. of Variables with a Theoretically-Consistent Sign for its Coefficient		7(12)*	6(10)	5(10)	5(10)	5(10)
Num. of Variables with a Significant Coefficient	SUM=	4(12)	4(10)	5(10)	4(10)	4(10)
	p<0.01	1 (EKB)	2 (EKB, PAS)	1 (EKB)	1 (EKB)	2 (EKB, AVECOM)
	p<0.05	-	2 (PS, AP2)	4 (COM, PAS,TEA, AP2)	1 (DEC)	1 (PAS)
	p<0.1	3 (DEC, PAS, AP2)	-	-	2 (PAS, AP2)	1 (AP2)
Pseudo R^2		0.672	0.597	0.603	0.656	0.659
Adjusted R^2		0.409	0.374	0.380	0.433	0.436
Hit rate		89.3%	90.5%	89.3%	89.3%	91.7%

* The number in the bracket is the number of the explanatory variables included in the model.

Our further discussion will be based on model 2E. For convenience, we replicate the estimation results of model 2E separately in Table 6-3-15.

Table 6- 3- 15: Probit Estimation Results for Model 2E (In-house vs. Outsourcing)

Probit regression	Number of obs = 84
Number of cases 'correctly predicted' = 77 (91.7%)	LR chi2(10) = 64.99
Log likelihood = -16.812	Prob > chi2 = 0.0000
Adjusted R^2=0.436	Pseudo R^2 = 0.659

	Predicted Sign	*Coefficient (Std. Error)*	*z*	*p-value*	
const		-13.747 (4.084)	-3.366	0.001	***
AVECOM	+	2.000 (0.739)	2.705	0.007	***
EKB	+	2.005 (0.575)	3.486	0.000	***
COD	+	-0.194 (0.410)	-0.473	0.636	
TEA	+	0.467 (0.433)	1.077	0.281	
SDK	+	-0.084 (0.248)	-0.339	0.734	
DU	+	-0.288 (0.383)	-0.753	0.452	
HAS	+	-0.240 (0.506)	-0.474	0.635	
PAS	+	1.066 (0.5027)	2.121	0.034	**
AP1	+	-0.421 (0.373)	-1.129	0.259	
AP2	+	0.722 (0.409)	1.765	0.078	*

*** p<0.01; ** p<0.05; * p<0.1

Table 6- 3- 16: Classification Table (Model 2E)

		Predicted		*Percentage Correct*
		0	1	
Actual	0	18	5	78.3
	1	2	59	96.7
Overall Percentage				91.7

Following a model selection procedure of sequential elimination (using two-sided p-value, alpha = 0.10), we further simplify the model specification on the basis of model 2E. Through this procedure, 6 less relevant variables are dropped[53]. As a result, we reach model 2F in which four variables remain.

The elimination of the 6 explanatory variables could be justified by testing jointly for their omission. The null hypothesis being that:

H_0: The regression parameters are all zero for the variables of DU, HAS, COD, TEA, SDK and AP1.

The likelihood ratio test shows up a Chi2(6)=3.536 with p-value=0.739, suggesting that the null hypothesis could not be rejected. In other words, the parameters for all the above 6 variable are not statistically different from zero and can therefore be dropped from regression.

We then estimate the new model 2F with the four retained variables. The results are presented in Table 6-3-17. In the new model, the coefficients for all the four variables are significant—for AVECOM and EKB, at the level of 1%; for PAS and AP2, significant at the level of 5%. Compared with model 2E, the significance level for AP2 is improved. In addition, in terms of Pseudo R^2, model 2F fits the data almost as well as model 2E (0.623 vs. 0.659), but with 6 less variables; while in terms of "hit rate", model 2F performs even better (92.9% vs. 91.7%).

[53] By the sequence of elimination, these variables are SDK, HAS, COD, DU, TEA and finally, AP1.

Table 6- 3- 17: Probit Estimation Results for Model 2F (In-house vs. Outsourcing)

Probit regression	Number of obs = 84
Number of cases 'correctly predicted' = 78 (92.9%)	LR chi2(4) = 61.46
Log likelihood = -18.58	Prob > chi2 = 0.0000
Adjusted R^2= 0.522	Pseudo R^2 = 0.623

	Predicted Sign	*Coefficient* (*Std. Error*)	*z*	*p-value*	
const		-13.667 (3.296)	-4.146	0.000	***
AVECOM	+	1.796 (0.558)	3.221	0.001	***
EKB	+	1.564 (0.394)	3.966	0.000	***
PAS	+	0.902 (0.413)	2.186	0.029	**
AP2	+	0.741 (0.375)	1.976	0.048	**

*** p<0.01; ** p<0.05; * p<0.1

Table 6- 3- 18: Classification Table (Model 2F)

		Predicted		*Percentage Correct*
		0	1	
Actual	0	19	4	82.7
	1	2	59	96.7
Overall Percentage				92.9

Marginal Effects

Based on model 2F, we calculate the marginal effect for each of the four variables at sample mean. Table 6-3-19 presents the results. More detailed expositions of the marginal effects (on a point-by-point incremental basis) are presented in Table 6-3-20, Figure 6-3-3 and Figure 6-3-4.

Table 6- 3- 19: Marginal effects at Sample Means (Model 2F)

$y = Pr(\text{ORM} = 1 \mid x = \bar{x}) = 0.874$

Variable	dy/dx (Std. Err.)	z	*p-value*	
AVECOM	0.371 (0.124)	2.99	0.003	***
EKB	0.323 (0.112)	2.88	0.004	***
PAS	0. 186 (0.084)	2.21	0.027	**
AP2	0.153 (0.085)	1.80	0.072	*

*** p<0.01, ** p<0.05, * p<0.1

Table 6- 3- 20: Marginal Effects of the Explanatory Variables on a Point-By-Point Incremental Basis† (Model 2F)

	1→2	2→3	3→4	4→5
AVECOM	0.417*	0.508	0.049	0.000
PAS	0.264	0.094	0.016	0.001*
EKB	0.057*	0.439	0.443	0.059
AP2	0.288*	0.237	0.116	0.033

† When calculating the marginal effect of a variable, other variables are held constant at their sample means.

* In the 84 observations, the value range for EKB and AP2 is 2 to 5, and for PAS, the value range is 1 to 4. AVECOM, being the average of PS, COM and DEC, varies from 1.333 to 4.

Figure 6- 3- 3: The Effects of the Point-by-Point Increase of Each Explanatory Variables on Pr(y=1) (Model 2F)

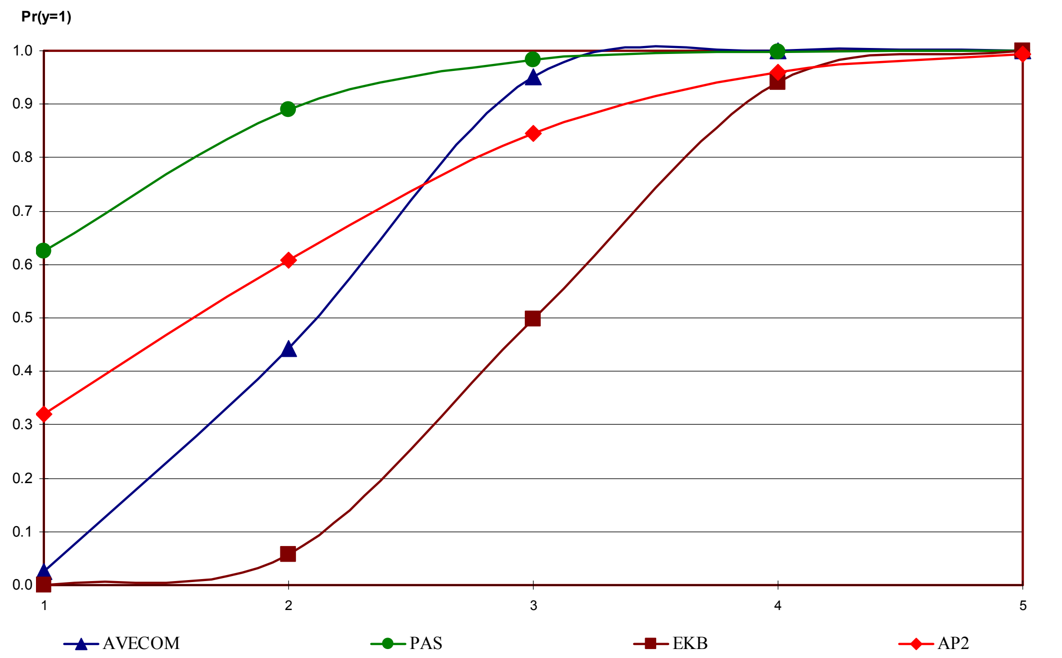
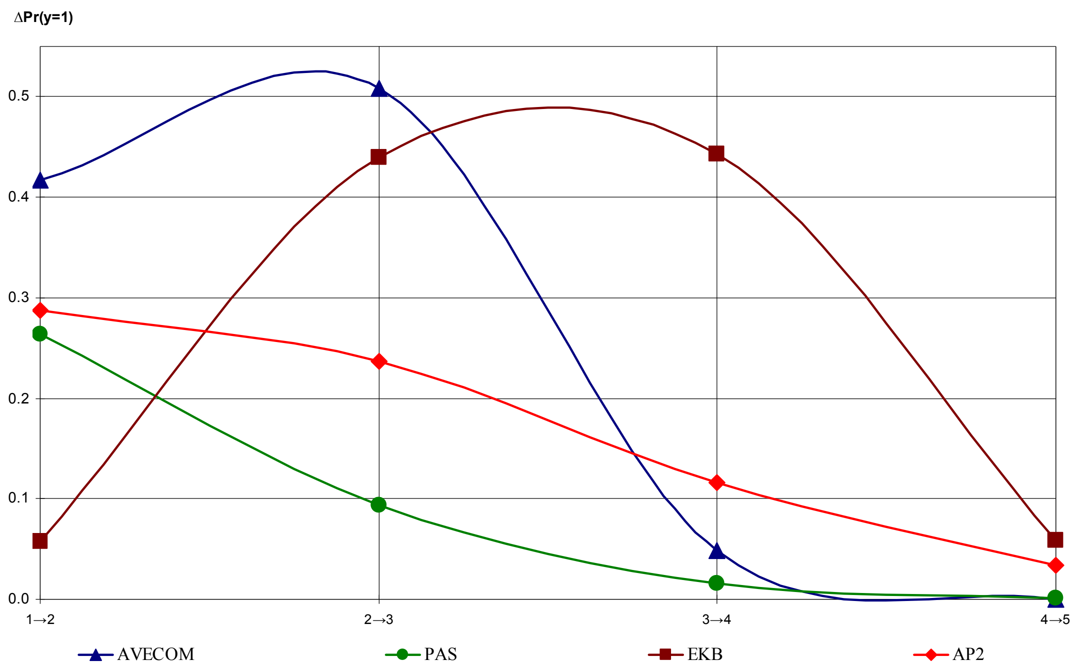


Figure 6- 3- 4: Marginal Effects of the Explanatory Variables on a Point-By-Point Incremental Basis*(Model 2F)



At sample means, the marginal effect of AVECOM is both strongest and most significant: a one-point increase in AVECOM adds to the probability of choosing in-house by 37.1%, and the effect is significant at the level of 1%. The marginal effect of EKB is also significant at the level of 1%. At sample means, a one-point increase in EKB would convert into a 32.3% higher probability of choosing in-house. By contrast, the strength of the marginal effects of PAS and AP2 are much weaker. For PAS, a one-point increase at means adds to the probability of choosing in-house by 18.7%, and the effect is significant at the level of 5%; while for AP2, the figure is 15.3%, and the effect is just marginally significant (at the level of 10%).

Table 6-3-20, Figure 6-3-3 and Figure 6-3-4 further reveal that for all the four variables, the marginal effects on a point-by-point incremental basis are far from being uniform.

For AVECOM and EKB, the marginal effects are bell-shaped. Specifically, when the value of AVECOM changes from 1 to 2 and from 2 to 3, the marginal increases in the predicted probability of choosing in-house are 41.7% and 50.8 % respectively. But the effect then dies down rapidly. As the value of AVECOM increases from 3 to 4, the marginal effect drops to less than 5%, and if AVECOM increases form 4 to 5, the marginal effect could hardly be discerned. The marginal effects of EKB share a somewhat similar pattern. When EKB changes from 2 to 3 and from 3 to 4, the marginal effect for each of the one-point increase is a more than 40% leap in the probability of choosing in-house. By contrast, the marginal effects for the first (1 to 2) and the last one-point increase (4 to 5) in EKB are much smaller (5.7% and 5.9% respectively).

The marginal effects of PAS and AP2, on the other hand, are monotonically decreasing. For PAS, the marginal effect of the first one-point increase (1 to 2) adds to the probability of choosing in-house by 26.4%, then the effects decline steadily, first to 9.4% (2 to 3), then to 1.6% (3 to 4), and finally to a negligible 0.1% (4 to 5). For AP2, when its value varies from 1 to 5, the corresponding marginal effects are 28.8%, 23.7%, 11.6% and 3.3%, respectively.

Summary and Discussion

Overall, the results are mixed.In the baseline model of 2A, of the five TCE variables, two (PAS and AP2) come up with a coefficient that bears the 'right' sign as predicted by the theory, and both of them are significant at the level of 10%. These results lend support to some of the transaction cost propositions. Specifically, a positive and significant coefficient for PAS implies that when a R&D project requires the investment in some highly specific physical assets, it is more likely that the project would be organized in-house rather than by market exchange. This is consistent with the prediction of transaction costs theory (P. Joskow, 1988; B. Klein et al., 1978; Riordan & Williamson, 1985; Williamson, 1979), in which the hierarchy (in-house) is thought to be more efficient in this circumstance because it mitigates the risk of being held-up by attenuating the opportunistic inclinations of the participating parties. While a positive and significant coefficient for AP2 means: the more appropriable the relevant knowledge is, the more likely the R&D project will be organized internally rather than through market. According to some transaction costs theory (Oxley, 1997; Teece, 1986), hierarchy (in-house) is chosen in this case because it is a more protective governance mechanism which provides better support for the utilization of appropriable knowledge.

Remember in the previous subsection, when the same set of explanatory variables are used to estimate a model that explains the choice between in-house and alliance, none of the TCE variables are found to be significant. We were a bit surprised at that time since there has been a vast body of empirical literature[54] in this field, which, as a whole, has been corroborative of the predictions of transaction cost economics. We then comment at the end of last subsection that we would take note and move on to see if similar results persist throughout.

On the basis of the above results, we can now conclude that as far as the choice between in-house and outsourcing (i.e., make-or-buy decision) is concerned, transaction costs considerations, such as appropriability hazard and physical asset specificity, are among the factors that would have a significant impact on the organizational choice of the R&D activities[55]. The results also suggest, compared with their role in previous circumstance (in-house vs. alliance), transaction costs considerations are far more decisive in the current make-or-buy decision[56].

[54] Surely, we note that most of these empirical researches are undertaken in the context of *make-or-buy* decision, and mainly focus on *manufacturing* activities, while our research is concerned with the organization of *R&D* activities, and in the previous sub-section, the choice to be made is between *in-house or alliance* rather *than make-or-buy*.

[55] It should be reminded that the other three transaction cost variables still fail to pass the significant tests.

In the preceding sub-section, in the context of the choice between in-house and alliance, we explore why transaction cost variables are not significant (p. 31). Some of the explanations we have considered, we believe, are still of relevance in the current circumstance. To repeat, unlike manufacturing, both the input and output of R&D activities are mostly non-specific to use or user. Supposedly, such non-specificity is more salient for human asset than for physical asset. Additionally, it is widely believed that the Chinese consumer electronics industry, the empirical setting of our research, has been in its mature stage, of which stable demand is one of the defining features. In other words, demand uncertainty might not be a issue at all in the context of this industry.

[56] To put this differently, our results suggest that transaction costs considerations (such as the avoidance of 'hold-up' problems, or the alleviation of appropriability hazard) matter for the make-or-buy decision. However, when the choice to be made is between in-house and alliance, neither asset

On the knowledge-based side, in the baseline model 2A, 5 out of the 7 KBV variables show up with a coefficient with the 'right' sign, 2 of which are significant.

Similar to that in the previous setting (in-house vs. alliance), the coefficient for EKB is again the most significant (at the level of 5%) among all explanatory variables. Specifically, a positive and significant coefficient for EKB suggests, as a firm has increasingly more complete knowledge that is required to solve a problem, it is more likely that the firm will organize the solution search for this problem internally rather than through market. Such a result is perfectly consistent with the prediction of the knowledge-based view (Argyres, 1996; Jacobides & Hitt, 2005; Madhok, 2002; Poppo & Zenger, 1998).

Apart from EKB, the coefficient for DEC has also been shown to be significant in the baseline model, but only at the level of 10%. As the three measures of complexity—PS, COM and DEC—are correlated with each other to some degree, multicollinearity is a concern. To avoid this potential problem, we try different model specifications by including only one of these three variables each time. It turns out that in each of the new specification, the coefficient for the complexity-related variable, either it be PS, COM, or DEC, is invariably significant at an improved level of 5%. In other words, as far as the choice between in-house and outsourcing is concerned, each of three complexity-related variables is seemingly equally valid in capturing the effects of complexity. We then estimate a fifth model in which the three complexity-related variables are replaced by a new composite construct AVECOM (defined as the average of PS, COM and DEC), and we find that the coefficient for this new variable is even more significant (at the level of 1%).

Overall, the above results tend to suggest the following few points. Firstly, the more complex the problem is (irrespective of measure), the more likely the problem-solving will be organized in-house rather than by market. This result is consistent with the prediction of the knowledge-based view (Macher, 2006; Luigi Marengo et al., 2000; Nickerson & Zenger, 2004). In addition, the results also reveal that each of the three dimensions of complexity (PS, COM and DEC) does play a non-negligible role in the make-or-buy decision. And finally; in the current setting, the overall effects of complexity are seemingly best captured by the composite measure of AVECOM. In terms of the significance level of its coefficient, it is one of the most decisive determinants that shape the make-or-buy decision.

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specificity and the associated hold-up problem, nor the appropriability hazard, is a big concern. This happens probably because alliances provide some sort of benefits that other modes of organization simply could not deliver, and such unique benefits overweight the possibly higher transaction costs associated with alliances.

Summing up, in this subsection of analysis, we try various model specifications, through some model selection process, we reach model 2E in which the coefficients for *four* out of the *ten* explanatory variables are estimated to be significant at the level of 10% or higher, of which two are TCE variables (PAS and AP2), and the other *two* are KBV variables (EKB and the composite variable AVECOM). Undoubtedly, the estimation results lend partial support to both theories. However, in terms of the strength of evidence (magnitude and significance level of their respective effects), it is still fair to say that KBV variables are playing a relatively more decisive role in the make-or-buy choice.

C. Alliance vs. Outsourcing

In this subsection, 81 observations (58 alliance and 23 outsource) are used to estimate a series of probit models to pin down the determinants that shape the choice between alliance and outsourcing. The descriptive statistics of the all the variables are presented in Table 6-3-21 and the correlations of the explanatory variables are presented in Table 6-3-22. As the choice between alliance and outsourcing is probably of less theoretical interest, analyses and discussions in this regard would not be as detailed as those for the first two choices (for example, we would skip the discussion on the marginal effects).

Table 6- 3- 21: Descriptive Statistics for All Variables (Alliance vs. Outsourcing)

Variable Code	Full Name	Mean (S.D.)			Min	Max
		Entire Samples	Alliance	Outsourcing		
Dependent Variable (1=Alliance; 0=Outsourcing)			**Num. of Obs.=81**			
ORM	Organization Mode	0. 716 (0.454)			0	1
Independent Variables						
PS	Problem Structure	2.617 (0.845)	2.793 (0.833)	2.174 (0.717)	1	4
COM	Complexity	3.432 (0.757)	3.655 (0.690)	2.870 (0.626)	2	5
DEC	Decomposability	2.383 (0.845)	2.552 (0.820)	1.957 (0.767)	1	5
EKB	Existing Knowledge Base	3.247 (0.845)	3.379 (0.721)	2.913 (1.041)	1	5
COD	Codifiability	2.840 (0.798)	2.914 (0.801)	2.652 (0.775)	1	5
TEA	Teachability	2.605 (0.801)	2.690 (0.730)	2.391 (0.941)	1	5
SDK	Social Distribution of Knowledge	3.136 (1.115)	2.897 (1.003)	3.739 (1.176)	1	5
DU	Demand Uncertainty	2.407 (0.919)	2.431 (0.920)	2.348 (0.935)	1	5
HAS	Human Asset Specificity	1.395 (0.646)	1.431 (0.678)	1.304 (0.559)	1	4
PAS	Physical Asset Specificity	1.852 (0.726)	1.966 (0.772)	1.565 (0.507)	1	4
AP1	Appropriability1	3.062 (0.966)	3.000 (0.991)	3.217 (0.902)	1	5
AP2	Appropriability2	3.062 (0.619)	3.103 (0.640)	2.957 (0.562)	2	5

Table 6- 3- 22: Correlation (Alliance vs. Outsourcing)

			PS	COM	DEC	EKB	COD	TEA	SDK	DU	HAS	PAS	AP1	AP2
1	**Problem Structure**	PS	1											
2	**Complexity**	COM	0.437	1										
3	**Decomposability**	DEC	0.680	0.676	1									
4	**Existing Knowledge Base**	EKB	-0.164	-0.130	-0.344	1								
5	**Codifiability**	COD	0.260	0.365	0.445	-0.219	1							
6	**Teachability**	TEA	0.365	0.244	0.429	-0.260	0.389	1						
7	**Social Distribution of Knowledge**	SDK	-0.209	-0.307	-0.268	-0.156	-0.158	-0.205	1					
8	**Demand Uncertainty**	DU	0.364	0.157	0.360	-0.099	-0.046	0.052	-0.079	1				
9	**Human Asset Specificity**	HAS	0.006	0.132	0.132	-0.112	0.246	0.209	-0.110	0.041	1			
10	**Physical Asset Specificity**	PAS	0.171	0.300	0.399	-0.103	0.498	0.285	-0.083	0.204	0.473	1		
11	**Appropriability1**	AP1	-0.338	-0.396	-0.397	0.272	-0.052	-0.194	-0.008	-0.268	-0.060	-0.218	1	
12	**Appropriability2**	AP2	-0.026	0.022	-0.070	0.257	-0.030	-0.076	0.060	-0.023	0.188	0.076	0.035	1

In the baseline model (3A), we include all the 12 explanatory variables. The estimation results are presented in Table 6-3-23. As shown in Table 6-3-23, the coefficients for three explanatory variables are estimated to be significant, of which 2 are (COM and PAS) at level of 5%, and one (EKB) at the level of 10%. Overall, Model 3A correctly predicts the organizational mode for 67 out of the 81 observations, yielding a hit rate of 82.7% (see Table 6-3-24)—a number 11% higher than if all observations were assigned to the most frequently observed structure (71.6%).

Table 6- 3- 23: Probit Estimation Results for Model 3A (Alliance vs. Outsource)

Probit regression	Number of obs = 81
Number of cases 'correctly predicted' = 67 (82.7%)	LR chi2(10) = 40.02
Log likelihood = -28.316	Prob > chi2 = 0.0000
Adjusted R^2=0.145	Pseudo R^2 = 0.414

	Predicted Sign	*Coefficient (Std. Error)*	*z*	*p-value*	
const		-5.957 (2.573)	-2.315	0.021	**
PS	+	0.525 (0.357)	1.473	0.141	
COM	+	1.109 (0.466)	2.379	0.017	**
DEC	+	-0.336 (0.508)	-0.663	0.508	
EKB	+	0.512 (0.293)	1.748	0.080	*
COD	(?)	-0.312 (0.315)	-0.989	0.323	
TEA	(?)	0.253 (0.312)	0.809	0.418	
SDK	(?)	-0.296 (0.206)	-1.436	0.151	
DU	(?)	-0.206 (0.258)	-0.799	0.425	
HAS	+	-0.130 (0.405)	-0.321	0.748	
PAS	+	0.875 (0.411)	2.129	0.033	**
AP1	+	0.063 (0.271)	0.232	0.816	
AP2	+	0.303 (0.406)	0.747	0.455	

*** $p<0.01$; ** $p<0.05$; * $p<0.1$

Table 6- 3- 24: Classification Table (Model 3A)

		Predicted		*Percentage Correct*
		0	1	
Actual	0	15	8	65.2
	1	6	52	89.7
Overall Percentage				82.7

As stated above, the binary choice between alliance and outsourcing is rarely examined separately, especially in a systematic way[57]. Therefore, it is not particularly clear in what way some of the explanatory variables are related to the outcome of the choice. For example, we don't know how codifiability might affect this choice. Would a higher degree of knowledge codifiability favour the choice of alliance, or the other way around?

However, for the following few variables, we are more certain of the direction of their effect.

As indicated above, alliance in general and joint venture in particular is probably the most expensive mode of organization. A firm tends to avoid such "hybrid" form of organization unless it has been proved absolutely necessary, or in other words, unless such hybrid form confers some benefits otherwise unattainable in other modes of organization. In our understanding, to get access to complementary knowledge, to overcome the capability bottlenecks, and to solve complex problems that go beyond existing capabilities of the firm, are probably the few most obvious benefits that are unique to alliance. Following this line of reasoning, it could be reasonably assumed that the more complex the problem is (irrespective of measure), the more likely the solution search for the problem will be organized by alliance rather than by market.

In addition, it is equally reasonable to argue that, compared with the knowledge requirement for an outsourcer if the R&D project is organized through market, alliance participation generally requires a higher level of existing knowledge in relevant fields. Put differently, a higher level of existing knowledge favours the choice of alliance rather than outsourcing, *ceteris paribus*.

Finally, we also believe that when a R&D project involves a higher degree of asset specificity or appropriability, it is less likely to be organized through market

[57] In the literature, there are at best passing discussions on this choice , e.g., Hamel, Doz & Prahalad (1989).

(outsourcing) rather than alliance. This argument could be justified by noting that, compared with outsourcing, alliance offers a wider range of administrative/control mechanisms in the face of hold-up or appropriability problem. Accordingly, under outsourcing, the threat of being held up or the risk of appropriability hazards is presumably higher than under alliance, *ceteris paribus.*

In light of the above discussions, in the baseline model of 3A, of the 8 variables whose direction of impact could be reasonably inferred from the theory, 6 come up with a "right" sign, 3 are significant at the level of 10% of higher.

As before, following a model selection procedure of sequential elimination using two-sided p-value (alpha = 0.10), we try simplifying the model by dropping less relevant variables. Through this procedure, 10 variables are dropped[58], as a result, we arrive at model 3B in which only two variables remain. We then estimate the new model and the results of are shown in Table 6-3-25. As we can see, in this new model, each of the two variables is significant at the improved level of 1%.

Table 6- 3- 25: Probit Estimation Results for Model 3B (Alliance vs. Outsourcing)

Probit regression	Number of obs = 81
Number of cases 'correctly predicted' = 66 (81.5%)	LR chi2(4) = 29.55
Log likelihood = - 33.556	Prob > chi2 = 0.0000
Adjusted R^2= 0.244	Pseudo R^2 = 0.306

	Predicted Sign	*Coefficient (Std. Error)*	*z*	*p-value*	
const		-5.298 (1.250)	-4.239	0.000	***
COM	+	1.175 (0.266)	4.411	0.000	***
EKB	+	0.635 (0.214)	2.969	0.003	***

*** p<0.01; ** p<0.05; * p<0.1

[58] By the sequence of elimination, these variables are AP1, HAS, DEC, TEA, AP2, COD, DU, SDK, PS and finally, PAS.

Table 6- 3- 26: Classification Table (Model 3B)

		Predicted 0	1	*Percentage Correct*
Actual	0	11	12	47.8
	1	3	55	94.5
Overall Percentage				81.5

To justify the dropping of the 10 variables, we test jointly for their omission. The null hypothesis being that:

H_0: *In model 3A, the regression parameters are all zero for the variables of PS, DEC, COD, TEA, SDK, DU, HAS, PAS, AP1 and AP2.*

The likelihood ratio test comes up with a Chi2 (10)=10.480 with p-value=0.399. Statistically, the null hypothesis could not be rejected and the parameters for the above 10 variables could all be assumed to be zero and be dropped from regression.

However, we note that PAS, whose coefficient is significant at the level of 5% in model 3A, is among the variables that have been dropped (although the last one) in the above model selection process. At the time when it is dropped, the p-value for its coefficient is 0.129—a value roughly on the verge of significance. A similar situation applies to PS, which is the last but one to be dropped from model 3A, and with an even smaller p-value for its coefficient (0.112). Meanwhile, we also observe that in the new model 3B, the "hit rate" for the outcome of outsourcing (see Table 6-3-26) is considerately lower than that in model 3A (65.2% vs. 47.8%), suggesting that the exclusion of PAS might have a strong (and biased) impact on the prediction of the outsourcing outcome.

Given these considerations, we loosen the model selection criteria a little bit and instead set the alpha level to 0.12. By this standard, four variables remain, and the estimation results of the new model (Model 3C) are presented in table 6-3-27.

Table 6- 3- 27: Probit Estimation Results for Model 3C (Alliance vs. Outsourcing)

Probit regression	Number of obs = 81
Number of cases 'correctly predicted' = 68 (84%)	LR chi2(4) = 34.61
Log likelihood = - 31.023	Prob > chi2 = 0.0000
Adjusted R^2= 0.255	Pseudo R^2 = 0.358

	Predicted Sign	*Coefficient* (*Std. Error*)	*z*	*p-value*	
const		-6.425 (1.434)	-4.48	0.000	***
PS	+	0.406 (0.255)	1.588	0.112	#
COM	+	0.876 (0.293)	2.990	0.003	***
EKB	+	0.710 (0.226)	3.140	0.002	***
PAS	+	0.505 (0.308)	1.640	0.101	#

*** p<0.01; ** p<0.05; * p<0.1; # <0.12

Table 6- 3- 28: Classification Table (Model 3C)

		Predicted		*Percentage Correct*
		0	1	
Actual	0	15	8	65.2
	1	5	53	91.4
Overall Percentage				84

Again, we test for the omission of variables. The null hypothesis being that:

H_0: *In model 3A, the regression parameters are all zero for the variables of DEC, COD, TEA, SDK, DU, HAS, AP1 and AP2.*

With no doubt[59], the null hypothesis could not be rejected and the results of the likelihood ratio test is as follows: Chi2 (8)=5.415 with p-value=0.712. [60]

[59] With two restrictions being removed, the null hypothesis would certainly not be rejected. Here, we are more concerned with the values of test statistic rather than the test result.

[60] In fact, we make a direct (maybe trivial) comparison of Model 3B and Model 3C.
On the basis of model 3C, we test the following hypothesis: *the parameters are zero for the variables PS and PAS in model 3C*. The result of the likelihood ratio test shows that Chi2(2) = 5.0648, with p-value = **0.079468**. (suggesting that the null hypothesis could be rejected, i.e, the two variables are jointly signficant so they could not be dropped from model 3C)
However, of the 3 model selection statistics (the Akaike Information Criterion or AIC; Schwarz's Bayesian Information Criterion or BIC, and Hannan–Quinn information criteria), 2 have improved.

Summing up, the message is: the two variables PAS and PS are on the verge of significance (around 10%)—statistically, it is justifiable to omit them, but their omission would noticeably reduce the "hit rate" for predicting one of the outcomes (outsourcing). On balance, it is still preferable to keep them, and by doing so, the "hit rate" of the model 3C is even better than model 3A[61].

Summary and Discussion

In this subsection, we estimate a few probit models to pin down the determinants underlying the choice between alliance and outsourcing. As this choice is rarely examined separately (both theoretically and empirically), it is not totally clear in what way each of the explanatory variables might affect the outcomes of the choice. However, at least for a few variables, the direction of the effect could be reasonably inferred from the theory.

In the baseline model 3A, of the 8 variables whose signs of coefficient could be reasonably inferred, 6 come up with the right sign, 3 are significant at the level of 10% or higher, of which 2 (COM and EKB) are KBV variables and 1 (PAS) TCE variables.

We move on to simplify the models by dropping less relevant variables. Through a model selection procedure of sequential elimination using two-sided p-value (alpha = 0.10), 10 variables are dropped, among which is PAS, whose coefficient is significant at the 5% level in model 3A.

In the new model 3B, each of the two remaining variable (COM and EKB) is significant at an improved level of 1%, but at the same time, the "hit rate" for the outcome of outsourcing is much lower than that in model 3A (65.2% vs. 47.8%), suggesting that the exclusion of PAS might have a strong (and biased) impact on the prediction of the outsourcing outcome.

We then loosen the model selection criteria by setting the alpha level to 0.12. By this standard, four explanatory variables remain and we arrive at model 3C. In this model,

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And the results of a Wald test (asymptotic test) shows that Wald chi2 (2) = 4.61587, with p-value = **0.0994664** and F-form: F(2, 76) = 2.30794, with p-value = 0.106399.
As a whole, these somewhat contradictory results suggest, it might not be perfectly appropriate to drop these two variables from model 3C.

[61] Admittedly, in terms of predictive power, none of the three models performs well enough. In the best case (3C), the overall "hit rate" is 84% (68 out of the 81 cases), a 12.4% higher than if all observations were assigned to the most frequently observed structure (71.6% %). However, it should be noted that the hit rates for the two outcome are sort of biased, for the alliance, it is as good as 91.4%, but for the other outcome (outsourcing), the hit rate is a much lower 65.2%.

all the explanatory variables are with a positive coefficient, of which COM and EKB are significant at the level of 1%, the other two variables PAS and PS are on the verge of significance (p=0.101 & 0.112 respectively), but the "hit rate" of model 3C is even better than model 3A.

The above results imply: (1) the more complex the problem is (either measured by COM or PS), the more likely the solution search for the problem will be organized by alliance rather than by market; (2) A higher level of existing knowledge (as measured by EKB) favours the choice of alliance rather than outsourcing, *ceteris paribus*; and (3) when a R&D project is supported by the investment in highly specific physical asset, it is less likely to be organized through market(outsourcing) rather than alliance.

Summing up, as far as the choice of alliance and outsourcing is concerned, hypothesis from both theoretical perspectives win some partial support from the estimation results. But again, KBV factors are seemingly playing more important roles.

6.4 Multinomial Analysis of the Organizational Choices

In the previous sections, the organizational choices are viewed as a series of binary choices, and we estimate these binary choices separately to identify the underlying determinants in each setting. In this section, the organizational choices are instead treated as polychotomous. Using all the 142 samples and in a more integrated framework, we estimate various multinomial models with the full choice set (3 or 4 choices) to pin down the determinants that shape the organizational choices of R&D. As we will see, the multinomial approach of this section, and the binomial approach of previous sections, are indeed methodologically consistent, each enjoying some advantages.

The section will be organized in the following order. We begin in 6.4.2, introducing various polychotomous choice models (multinomial logit, conditional logit and nested logit) and their underlying assumptions, highlighting the rationale for the choice of the multinomial logit model. We then discuss (6.4.2) at some length the technical details of the multinomial model (including its derivation, identification, interpretation of coefficients and marginal effects). To justify our approach, we further discuss (6.4.3) the methodological consistency of the simultaneous use of multinomial and binomial estimation. On the basis of these technical discussions, we present in the final subsection the results and analyses of the multinomial estimations (6.4.4). Specifically, the analyses consist of two parts, each corresponding to a classification of the dependent variable. In the first classification, the dependent variable—organizational mode—is divided into three categories: in-house, alliance and outsourcing. In the second classification, alliances are further differentiated into two types: the equity-based alliance and the contract-based alliance. Based on these two different classifications, we estimate two sets of multinomial logit models. As we will see, both classifications have their justifications and there is no overwhelmingly evidence that one is absolutely better than the other. Nevertheless, both sets of models contribute to our understanding of the underlying determinants that shape the organizational choices of R&D activities.

6.4.1. Choosing the Right Model: Multinomial logit, Conditional Logit and Nested Logit

In economic research, dependent variables can often be a finite number of values which have no natural order. This applies to a context when an agent is to choose from a set of unordered alternatives. When ***all*** the explanatory variables deal with ***case-specific attributes*** (also known as ***individual-specific characteristics***) that do not vary across alternatives (these variables are known as ***alternative invariant regressors***), the *multinomial logit* (*MNL*) is the appropriate model. If the explanatory variables also involve ***choice-specific attributes*** (these variables are known as ***alternative varying regressors***)—that is, variables that vary across alternatives and possibly across the individuals as well—the *conditional logit* (*CL*) is the appropriate model (Cameron & Trivedi, 2005; W. H. Greene, 2008).

For example, in a model, travellers choose among a set of travel modes: “bus”, “train”, “car” and “plane”. Suppose in this model, there are two explanatory variables: “travel time” and “travel costs”. “Travel time” depends on the travel mode (but not on individual’s characteristics), it is a ***choice-specific attribute*** and its value varies across alternatives. While “travel costs” depends not only on the travel mode, but also on individual income through opportunity costs. Therefore, “travel costs” is an ***individual-specific characteristic***. In this example, as an ***alternative varying regressor*** is being included, the *conditional logit* would be the appropriate model.

If, in another model, travellers choose among the same set of travel modes but ***all*** the explanatory variables describe the characteristics of travellers which are invariant across alternatives (such as income, gender and age), and there is no information on the travel modes. In this case, as only ***alternative-invariant regressors*** are being used, *the multinomial logit (MNL)* is the appropriate model.

It should be highlighted that for both the multinomial logit and the conditional logit models, the IIA property (***independence of irrelevant alternatives***) [62] holds (McFadden, 1974). Specifically, the IIA property states that the odds ratio between any two alternatives does not depend on absence/presence of other alternatives. In other words, the ratio of the probabilities for alternative *j* and *m* (P_j / P_m) is the same, irrespective of what other alternatives are in the choice set, or what the characteristics of the other alternatives are; adding new alternative or changing the characteristics of a third alternative does not affect the odds ratio of P_j / P_m (Luce & Suppes, 1965).

This property of IIA is convenient for estimation, but it is not always appropriate. Specifically, for applications with similar alternatives, IIA is particularly implausible and may not properly reflect the behavioural relationships among groups of alternatives. McFadden's famous red bus/blue bus example illustrates this point (McFadden, 1980). Specifically, suppose z_1, z_2 and z_3 are the attributes of a trip by car, red bus and blue bus, respectively. Further suppose the commuters are indifferent between car and bus and treat the two buses as equivalent. Initially, commuters face a decision between two options: car and red bus. In this case, one expect,

$$P(Car \mid z_1, z_2) = P(Red\ Bus \mid z_1, z_2) = 1/2$$

and the odds ratio for these two options is

$$P(Car \mid z_1, z_2) / P(Red\ Bus \mid z_1, z_2) = 1$$

If blue bus is added as third option, as it has been assumed that consumers do not care about the colour of the bus, we expect,

$$P(Car \mid z_1, z_2, z_3) = 1/2,\ P(Red\ Bus \mid z_1, z_2, z_3) = 1/4, \text{ and } P(Blue\ Bus \mid z_1, z_2, z_3) = 1/4$$

and the odds ratio for the first two options is now

$$P(Car \mid z_1, z_2, z_3) / P(Red\ Bus \mid z_1, z_2, z_3) = 2\ .$$

[62] The IIA property of the MNL and CL model follows from the assumption that the random terms of the utility function are identically and independently distributed. For technical details, see Ben-Akiva and Lerman (1985) and Green (2008) Ch 23.

In other words, the odds ratio of alternative 1 (car) and 2 (red bus) depends on the presence of alternative 3 (blue bus), and this result is inconsistent with the property of IIA. If the IIA were not violated, it requires the odds ratio between taking a car versus a red bus to be preserved, and this in turn implies that the probability for each of the three options is 1/3. Intuitively, the problem with the IIA property is that it fails to take account of the possibility that some alternatives could be highly similar, or even be "perfect substitutes", therefore imposing an implausible restriction on choice making behaviour.

For choice-making that violates IIA, the multinomial logit and the conditional logit model are no longer appropriate[63] (Amemiya, 1981; McFadden, 1974, 1980). In this circumstance, other models such as nested logit, HEV (heteroscedastic extreme-value), mixed logit or multinomial probit, which relax the IIA property in different ways, can be used to accommodate choice-making that are not consistent with IIA (Train, 2003).

In the context of our research, and in light of the empirical evidence on this topic, (1) we believe that the dependent variable (organizational mode of R&D activities) is better viewed as a set of unordered choices; (2) we further note that the explanatory variables in our model deal only with *case-specific characteristics* and not with *choice-specific attributes*; (3) and finally, we don't think any pair of organizational modes in our research are close substitutes. Based on these considerations, we think the multinomial logit is the appropriate model for our study. In the text that follows, I will concentrate on the multinomial model.

6.4.2. Multinomial Logit Model: Some Technical Notes

A. Derivation of the Multinomial Logit Model from the ARUM Framework

Discrete choice models can be derived from the general framework of ***additive random utility model*** **(ARUM)** in which the agents are assumed to be utility maximizers[64] (Ben-Akiva & Lerman, 1985; Cameron & Trivedi, 2005; Train, 2003) The basic setup is as follows:

[63] These practical limitations led McFadden to suggest that the assumption of IIA implies that the application of multinomial and conditional logit models "should be limited to situations where the alternatives can plausibly be assumed to be distinct and weighted independently in the eyes of each decision maker." (1974: p. 113)

[64] In the context of current research, the agent's (the firm) problem is to choose among a set of organizational modes to minimize the expected costs of governing certain productive activities over their durations. In short, the firm's problem is a ***cost minimization problem***.

It should be noted that a cost minimization problem could be treated as dual to a utility maximization problem.

An agent i, faces a set of choices among J alternatives. The agent obtains a certain level of utility from each alternative. The (indirect) utility that agent i obtains from alternative j is given by

$$U_{ij} = V_{ij} + \varepsilon_{ij}, \quad j = 1, 2, \ldots, J \tag{6.11}$$

where V_{ij} denotes the deterministic component of utility and ε_{ij} denotes the random component of utility. The agent i choose alternative j if $U_{ij} \geq U_{im} \ \forall \ m \neq j$.

This utility is known to the agent but not to the analyst, but the analyst can observe some characteristics of the agent and/or some attributes of the alternatives. In the case of the multinomial logit, the variables describe characteristics of the individuals but not the alternatives, so the deterministic component is given by

$$V_{ij} = x_i' \beta_j \tag{6.12}$$

where x_i describes the characteristics of the individual and is identical across alternatives, β_j is the parameter vector which differs across alternatives.

The probability that agent i choose alternative j can be written as:

$$\begin{aligned} P_{ij} &= Prob(U_{ij} \geq U_{im} \ \forall \ m \neq j) \\ &= Prob(V_{ij} + \varepsilon_{ij} \geq V_{im} + \varepsilon_{im} \ \forall \ m \neq j) \\ &= Prob(\varepsilon_{im} - \varepsilon_{ij} \leq V_{ij} - V_{im} \ \forall \ m \neq j) \end{aligned} \tag{6.13}$$

This probability is a cumulative distribution, namely, the probability that each random term $\varepsilon_{im} - \varepsilon_{ij}$ is below $V_{ij} - V_{im}$. Denote the joint density of the random vector $\varepsilon_i = \{\varepsilon_{i1}, \varepsilon_{i2}, \ldots, \varepsilon_{iJ}\}$ as $f(\varepsilon_i)$. Using the density $f(\varepsilon_i)$, this cumulative probability can be rewritten as:

$$P_{ij} = \int \cdots \int_{\mathbb{R}^J} I(\varepsilon_{im} - \varepsilon_{ij} \leq V_{ij} - V_{im} \ \forall \ m \neq j) f(\varepsilon_i) d\varepsilon_{iJ} \cdots d\varepsilon_{i1} \tag{6.14}$$

Thus, our problem (see 11.4.4.A for a more detailed description) is fully compatible with the ***additive random utility model*** (ARUM) framework.
For the generality of discussion, we use the ARUM framework to show how the multinomial logit model is obtained.

where $I(\cdot)$ is the indicator function equal to 1 when the expression in parenthesises is true and 0 otherwise.

For example, consider agent i's probability of choosing alternative 1 in a J alternatives model, the exact expression for the integral is:

$$\begin{aligned} P_{i1} &= Prob(y_i = 1 \mid x_i) \\ &= Prob(U_{i1} \geq U_{im} \quad \forall\, m \neq 1) \\ &= Prob(U_{i1} \geq U_{i2}, \cdots, U_{i1} \geq U_{iJ}) \\ &= Prob(\varepsilon_{i1} + x_i'\beta_1 - x_i'\beta_2 \geq \varepsilon_{i2}\ , \cdots, \varepsilon_{i1} + x_i'\beta_1 - x_i'\beta_J \geq \varepsilon_{iJ}) \\ &= \int_{-\infty}^{\infty} \int_{-\infty}^{\varepsilon_{i1}+x_i'\beta_1-x_i'\beta_2} \cdots \int_{-\infty}^{\varepsilon_{i1}+x_i'\beta_1-x_i'\beta_J} f(\varepsilon_{i1}, \varepsilon_{i2}, \cdots, \varepsilon_{iJ}) d\varepsilon_{iJ} \cdots d\varepsilon_{i2} d\varepsilon_{i1} \end{aligned} \quad (6.15)$$

Different discrete choice models are obtained from different specifications of density $f(\varepsilon_i)$, that is, from different assumptions about the distribution of the unobserved portion of utility.

The multinomial logit model is obtained by assuming that each ε_{ij} is distributed iid extreme value (Gumbel distribution or Type-I extreme value distribution). The probability density function (PDF) for ε_{ij} is:

$$f(\varepsilon_{ij}) = \exp(-\varepsilon_{ij}) \exp[-\exp(-\varepsilon_{ij})] \quad (6.16)$$

and the cumulative distribution is:

$$F(\varepsilon_{ij}) = \exp[-\exp(-\varepsilon_{ij})] \quad (6.17)$$

It should be noted that the difference between two independent extreme value variables is distributed logistic, i.e., if ε_{im} and ε_{ij} are iid extreme value, then $\tilde{\varepsilon}^i_{mj} = \varepsilon_{im} - \varepsilon_{ij}$ has a logistic distribution, i.e.,

$$F(\tilde{\varepsilon}^i_{mj}) = \frac{e^{\tilde{\varepsilon}^i_{mj}}}{1 + e^{\tilde{\varepsilon}^i_{mj}}} \quad (6.18)$$

Using the above properties and solve the integral in (6.14) (for technical details, see Train, 2003, section 3.10), we have the following closed-form expression[65] for the probability that agent *i* choose alternative *j*:

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_l e^{V_{il}}} = \frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}} \tag{6.19}$$

An interesting feature of the multinomial logit model is that the odds ratio of two alternative *j* and *m* depends log-linearly on x_i. Specifically,

$$\begin{aligned} ln\left(\frac{P_{ij}}{P_{im}}\right) &= ln\left(\frac{\exp(x_i'\beta_j)\Big/\sum_{l=1}^{J}\exp(x_i'\beta_l)}{\exp(x_i'\beta_m)\Big/\sum_{l=1}^{J}\exp(x_i'\beta_l)}\right) \\ &= \ln\left(\exp\left[x_i'(\beta_j-\beta_m)\right]\right) \\ &= x_i'(\beta_j-\beta_m) \end{aligned} \tag{6.20}$$

B. Identification

In the multinomial logit model, the parameter vectors β_j , $j = 1, 2, \ldots, J$ are not uniquely identified. To illustrate, let us define $\beta_j^* = \beta_j + q \;\; \forall \; j$, where q is an arbitrary vector of constants, we will find that exactly the same set of probabilities would be produced whether we use β_j or β_j^*, since all the terms involving q drop out.

$$\begin{aligned} P_{ij}^* &= \frac{\exp[x_i'(\beta_j+q)]}{\sum_{l=1}^{J}\exp[x_i'(\beta_l+q)]} \\ &= \frac{\exp(x_i'\beta_j)\exp(x_i'q)}{\sum_{l=1}^{J}[\exp(x_i'\beta_l)\exp(x_i'q)]} \\ &= \frac{\exp(x_i'\beta_j)\exp(x_i'q)}{\left[\sum_{l=1}^{J}\exp(x_i'\beta_l)\right]\exp(x_i'q)} \end{aligned}$$

[65] It should be noted that the integral takes a closed form only for certain specifications of $f(\cdot)$. Multinomial logit (as we are demonstrating now) and nested logit have closed-form expressions for this integral. But for Multinomial probit or mixed logit, the resulting integral does not have a closed form.

$$= \frac{\exp(x_i'\beta_j)}{\sum_{l=1}^{J}\exp(x_i'\beta_l)} = P_{ij} \tag{6.21}$$

Given this property, a convenient normalization that solves the identification problem is to assume that the coefficients for one of the alternatives m are all zero (i.e., $\beta_m = 0$), thus setting it as the base of reference. All the other parameters can then be interpreted with reference to that base. Suppose we set $\beta_1 = 0$ (that is, all of the coefficients for alternative 1 are set to be 0), the probability that agent i choose alternative j could then be written as:

$$P_{ij} = \frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}, \text{ where } \beta_1 = 0 \tag{6.22}$$

Since $e^{x_i'\beta_1} = e^0 = 1$, we have:

$$P_{i1} = \frac{e^{x_i'0}}{e^{x_i'0} + \sum_{l=2}^{J} e^{x_i'\beta_l}} = \frac{1}{1 + \sum_{l=2}^{J} e^{x_i'\beta_l}} \tag{6.23}$$

and

$$P_{ij} = \frac{e^{x_i'\beta_j}}{1 + \sum_{l=2}^{J} e^{x_i'\beta_l}} \text{ for } j \neq 1 \tag{6.24}$$

Hence, for $j = 2, 3, \ldots, J$

$$\frac{P_{ij}}{P_{i1}} = \frac{e^{x_i'\beta_j} \Big/ \left(1 + \sum_{l=2}^{J} e^{x_i'\beta_l}\right)}{1 \Big/ \left(1 + \sum_{l=2}^{J} e^{x_i'\beta_l}\right)} = e^{x_i'\beta_j} \tag{6.25}$$

and we can compute the $J-1$ log-odds ratios

$$ln\left(\frac{P_{ij}}{P_{i1}}\right) = x_i'\beta_j \tag{6.26}$$

C. Interpretation of Coefficients and Marginal Effects

In the multinomial logit model, neither the sign nor the magnitude of the coefficient has a direct and intuitive meaning. As a consequence, hypothesis tests have to be very carefully formulated in terms of the estimated coefficients.

Let us start by looking at the marginal effects of the explanatory variables. Specifically, for agent i, the marginal effect of the k^{th} explanatory variable x_k on the probability of choosing alternative j is

$$\begin{aligned}
\frac{\partial P_{ij}}{\partial x_{ik}} &= \frac{\partial P(y_i = j \mid x_i)}{\partial x_{ik}} \\
&= \frac{\partial\left(\dfrac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}\right)}{\partial x_{ik}} \\
&= \frac{\left(\beta_{jk} e^{x_i'\beta_j}\right)\sum_{l=1}^{J} e^{x_i'\beta_l} - e^{x_i'\beta_j}\sum_{l=1}^{J}\left[\beta_{lk} e^{x_i'\beta_l}\right]}{\left[\sum_{l=1}^{J} e^{x_i'\beta_l}\right]^2} \\
&= \beta_{jk}\frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}} - \frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}\frac{\sum_{l=1}^{J}\left[\beta_{lk} e^{x_i'\beta_l}\right]}{\sum_{l=1}^{J} e^{x_i'\beta_l}} \\
&= \beta_{jk}\frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}} - \frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}\sum_{l=1}^{J}\left[\frac{\beta_{lk} e^{x_i'\beta_l}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}\right] \\
&= \beta_{jk}\frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}} - \frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}\sum_{l=1}^{J}\left[\beta_{lk}\left(\frac{e^{x_i'\beta_l}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}\right)\right] \\
&= P_{ij}\left(\beta_{jk} - \sum_{l=1}^{J}\beta_{lk}P_{il}\right) \\
&= P_{ij}(\beta_{jk} - \bar{\beta}_k)
\end{aligned} \tag{6.27}$$

where $\bar{\beta}_k = \sum_{l=1}^{J}\beta_{lk}P_{il}$ is a probability weighted average of the k^{th} coefficient for all alternatives.

As we can see, the sign of the marginal effect depends not only on the parameter β_{jk} but also on $\bar{\beta}_k$. Therefore, the sign of the marginal effect is not necessarily the same as that for the coefficient β_{jk},

A more direct interpretation of the coefficient can be obtained by looking at the log of the odds ratio.

As given by (6.20)

$$ln\left(\frac{P_{ij}}{P_{im}}\right) = x_i'(\beta_j - \beta_m)$$

taking derivative of (6.20) with respect to *the* k^{th} explanatory variables x_k. We have

$$\frac{\partial ln(P_{ij} / P_{im})}{\partial x_{ik}} = \beta_{jk} - \beta_{mk} \tag{6.28}$$

which reduces to

$$\frac{\partial ln(P_{ij} / P_{i1})}{\partial x_{ik}} = \beta_{jk} \tag{6.29}$$

when alternative 1 is set as the reference category (i.e., $\beta_1 = 0$).

Therefore, a positive coefficient β_{jk} means an increase in x_k increases the relative probability of choosing alternative *j* over alternative 1 (base).

6.4.3. The Consistency of Binomial Estimation and Multinomial Estimation: Some Methodological Considerations

In previous stage, we estimate a series of binomial probit models, each based on a subset of the 142 observations. This stage, we would instead estimate the multinomial logit model using all the 142 observations. Naturally, one might wonder to what extent the first stage binomial model is methodologically consistent with the second stage multinomial model. In this subsection, we will demonstrate that multinomial logit and binomial logit are methodologically consistent, although each enjoys certain nuanced advantages.

Note that in the first stage estimation, we use binomial ***probit*** rather than ***logit***, and it is certainly less consistent to compare the binomial probit with the multinomial logit. We are aware of this issue. However, as we have noted above[66], in practice, binomial probit and logit models produce highly compatible results, either in terms of the sign and significance level of the estimated coefficients, or in terms of the magnitude of

[66] See footnote 33.

the marginal effects for the explanatory variables. Given this, we believe that our methodology is essentially sound and well-justified.

The multinomial logit model can be viewed as simultaneously estimating a series of binomial logit models for all the possible pair-wise combinations of the outcome categories (Long, 1997; Long & Cheng, 2004). In fact, in both the statistical (Begg & Gray, 1984) and econometric literature (Alvarez & Nagler, 1998; Amemiya, 1976; Ben-Akiva & Lerman, 1985; Hausman & McFadden, 1984), it has been an established result that both binomial logit and multinomial logit consistently estimate essentially the same parameters.

To be more exact, if the multinomial logit model is correctly specified, consistent estimates of the same sub-vector of parameters can be obtained from both a multinomial logit model estimated with a full choice set, and from another multinomial logit or binomial logit model estimated with a restricted choice set (Ben-Akiva & Lerman, 1985: p. 184). For example, for a choice problem with three outcomes, if the model was correctly specified, both the multinomial logit on the full choice set and the binomial logit on each restricted choice set (each pair of choices) would yield consistent estimates of the same parameters (Hausman & McFadden, 1984). In short, in this case, a multinomial logit is roughly equivalent to running three binomial logits.

More generally, as given by (6.19), in a multinomial model with J outcomes, the probability that agent i choose alternative j is:

$$P_{ij} = \frac{e^{x_i'\beta_j}}{\sum_{l=1}^{J} e^{x_i'\beta_l}}, \quad j = 1, 2, \cdots, J$$

The conditional probability of observing outcome j given that either outcome j or outcome m is observed can be derived form (6.19), i.e.,

$$\begin{aligned} Prob[y_i = j \mid y_i = j \ or \ m] &= \frac{P_{ij}}{P_{ij} + P_{im}} \\ &= \frac{e^{x_i'\beta_j}}{e^{x_i'\beta_j} + e^{x_i'\beta_m}} \\ &= \frac{e^{x_i'(\beta_j - \beta_m)}}{1 + e^{x_i'(\beta_j - \beta_m)}} \end{aligned} \qquad (6.30)$$

Alternatively, (6.30) can be written in terms of logit[67]

$$\ln\left(\frac{Prob[y_i = j \mid y_i = j \ or \ m]}{1-Prob[y_i = j \mid y_i = j \ or \ m]}\right) = \ln\Omega_{j|m}(x_i)$$

$$= \ln\left(e^{x_i'(\beta_j - \beta_m)}\right) \quad (6.31)$$

$$= x_i'(\beta_j - \beta_m) = x_i'\beta_{j|m}$$

Indeed, (6.31) is a logit model of the binary choice between outcome *j* and *m*, and the coefficient is $(\beta_j - \beta_m)$.

Suppose outcome 1 set as the base category in the multinomial model, and β_1 is accordingly normalized to 0. Equation (6.30) becomes

$$Prob[y_i = j \mid y_i = j \ or \ 1] = \frac{e^{x_i'\beta_j}}{1+e^{x_i'\beta_j}} \quad (6.32)$$

And from (6.31), we have

$$\begin{aligned}\ln\Omega_{j|1}(x_i) &= x_i'(\beta_j - \beta_1) = x_i'(\beta_j - 0) \\ &= x_i'\beta_j = x_i'\beta_{j|1}\end{aligned} \quad (6.33)$$

Obviously, the coefficient for alternative *j* in the multinomial model β_j can be equivalently interpreted as the coefficient of a binomial logit model for the choice between outcome *j* and 1(base category).

There is, however, one complication. In the multinomial logit model, all of the logits are estimated simultaneously and using all the observations. While the corresponding binomial logit models are estimated with smaller samples, as each time observations from only two of the outcomes are used in estimation. In other words, when estimating each of the binomial logit, we compare only two of the outcomes, and those samples that choose other outcomes are dropped. In doing so, some information is discarded, and there is a loss of efficiency accordingly. By contrast,

[67] In the binomial logit model, $\Omega(x_i) = \frac{Prob(y_i = 1 \mid x_i)}{Prob(y_i = 0 \mid x_i)} = \frac{Prob(y_i = 1 \mid x_i)}{1 - Prob(y_i = 1 \mid x_i)}$ measures the probability that y = 1 relative to the probability that y = 0 and is called the *odds ratio* or *relative risk*. The log of the odds ratio $\ln\Omega(x_i)$ is called the Logit.

the multinomial logit model makes better use of the available information and it produces more efficient[68] estimates (Allison, 1999; Alvarez & Nagler, 1998).

Summing up, the point is, once IIA is assumed, and given that the models are correctly specified, both multinomial and binomial logit models produce consistent estimates of the same set of parameters. In this sense, multinomial is no richer than the binomial logit models (Alvarez & Nagler, 1998).

That being said, it is still worth noting that each of the two models enjoys some nuanced advantages. The advantage of multinomial logit is obvious. As just illustrated, in an integrated framework and using all the observations, the multinomial logit model produces more efficient estimates than its corresponding binomial logit counterparts. Relatedly, by fitting all the data in an integrated model rather than fitting overlapping subsets of data for several binomial models, the multinomial logit model gives one likelihood ratio χ^2 for the fit of entire model, which in turn makes possible some testings on groups of coefficients that the corresponding binomial models are simply not capable of (e.g., testing the effect of one or more independent variables[69], or testing whether the independent variables as a group differentiate between two outcomes[70]).

On the other hand, to approximate the fit of a multinomial logit model by fitting separate binary models is not without its own advantages (Begg & Gray, 1984; Hosmer & Lemeshow, 2000). As have been noted at the beginning of this chapter, even in a three outcomes multinomial model, the choice between outcome A and C might entails quite different issues than those for the choice between B and C. As a result, the estimated coefficient for some explanatory variable could be significant for the choices between outcome A vs. C but not B vs. C. In a more general many outcomes model, it is possible that the coefficient for an explanatory variable is

[68] It is more efficient in the sense that all other things being equal, the variance of the multinomial logit estimates are smaller than that of the binomial logit estmates.

[69] To be more exact, the testing is about whether one or more variables have effect on the dependent variable. For a *J* outcomes multinomial logit model, the testing that a variable has no effect requires a test that *J-1* coefficients are simultaneously equal to zero. Specifically, the hypothesis that an explanatory variable x_k does not affect the dependent variable can be written as:

$H_0 : \beta_{k,j|b} = 0\ \forall j \neq b, j = 1, 2, \cdots, J$ *where b is the base category, and* $\beta_{k,j|b}$ *is the coefficient for* x_k *under outcome j.* The hypothesis imposes constraints on *J-1* coefficients.

[70] Outcome *m* and *n* are indistinguishable with respect to the explanatory variables in the model if none of the explanatory variables significantly affect the odds of outcome *m* versus outcome *n* (Anderson 1984) . The hypothesis that outcomes m and n are indistinguishable can be written as:

$H_0 : \beta_{1,m|n} = \cdots = \beta_{K,m|n} = 0$, *where K is the number of explanatory variables (not including constant) in the model, and* $\beta_{k,m|n}$ *is the coefficient for* x_k *under outcome m when outcome n is set as the base category.*

significant for only one pair of the categories but not others. In this case, if we—based on the results of some econometric test—try to search for a more parsimonious model by excluding highly insignificant variables, we might find that while the overall test might indicate that as a *group* the coefficients are not significantly different from zero, an *individua*l coefficient can still be substantively and statistically significant (Long & Freese, 2006; p. 235). In this circumstance, there is an ambiguity about what it really means by saying "a correctly specified model". It is also difficult to judge whether such a variable should be included in the model, since once a variable is included, it is included not for just one outcome, but instead for all the outcomes. This problem is most obvious when calculating the marginal effects. For those outcomes under which the variable is insignificant, including this variable is seemingly doing nothing good but adding noises to the marginal effects of other truly significant variables.

Partly on this ground, we find it justifiable to view the organizational choice as a series of binary choices, and to start our analysis by estimating separately these binomial models to better capture the effects of the explanatory variables in each setting before moving on to estimate a multinomial model with the full choice set.

6.4.4. Results and Analysis of the Multinomial Estimations

In this section, we will present the estimation results and analysis for the multinomial models. This section of analysis consists of two parts, each corresponding to a classification of the dependent variable. In the first classification, the dependent variable—organizational mode—is divided into three categories: in-house, alliance and outsource. In the second classification, alliances are further differentiated into two types: namely the contract-based alliance and the equity-based alliance. Based on these two different classifications, we estimate separately two sets of multinomial logit models.

Such a two-specification arrangement could be justified on two grounds. On a practical level, both the three-category (for example, Narula, 2001a, 2001b; Robertson & Gatignon, 1998) and the four-category classifications (Colombo, 2003; Colombo & Delmastro, 2001; Colombo, Grilli, & Piva, 2006; Mowery, Oxley, & Silverman, 1998; Oxley, 1997; Gary P. Pisano, 1989, 1990, 1991) have been adopted in the empirical research. Behind each classification, there is a distinct branch of literature. By estimating these two different model specifications, a direct comparison of our results with these two branches of literatures could be facilitated. More importantly, as will become clearer later on, from a statistical or econometric point of view, both classifications could be partially supported[71], and there is not overwhelmingly evidence that which one is absolutely better.

A final and more technical concern is how to organize the results. From a statistical point of view, it might be more natural to start by estimating the four-category multinomial logit model on the basis of the raw data[72], and then move on to perform a test to examine whether the two types of alliance could be combined. In case the two categories could be combined, we proceed to estimate the three-category multinomial logit model. However, for the purpose of presenting the results, it might be more convenient to begin with the relatively simpler three-category multinomial logit, and then proceed to estimate the four-category model to see if the further differentiation of the two types of alliance provides any interesting new results.

The text in this subsection would thus be organized in the following order: in part A, we describe briefly our model specification; in part B, we present the results and analyses for the three-category multinomial logit estimations; in part C, we discuss some diagnostic testings for the multinomial logit model, in particular, tests for combining dependent categories and tests of IIA assumption; in part D, we present the results and analyses for the four-category multinomial logit estimations.

A. Model Specification

In our model, the firms' cost of organizing i^{th} R&D project under mode j is given by:

$$C_{ij} = x_i'\beta_j + \varepsilon_{ij} \tag{6.34}$$

where,

x_i is a vector of independent variables which describe certain characteristics of the i^{th} R&D project (including a value 1 corresponding to a constant term, i.e.. x_{i1}=1); x_i is invariant with respect to alternative;

β_j is a vector of coefficients for each of the independent variables (including the constant term) which differs across alternatives;

ε_{ij} is a random term.

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[71] However, it might still be fair to comment that, as a whole, the evidence in support of the four-category classification is relatively stronger.

[72] In our questionnaire, organization modes are defined as a four-category response variable.

The firms' decision rule for the choice is given as: project *i* will be organized by mode *j* if

$$C_{ij} \le C_{im} \ \forall \ m \ne j \qquad (6.35)$$

The cost function (6.34) is known to the agents but not the researcher, but the researcher can observe the firm's choice, and the characteristics of the R&D project x_i.

Suppose ε_{ij} is distributed iid extreme value (Gumbel distribution), we have the following multinomial model

$$\begin{cases} P_{ij} = Prob(ORM_i = j \mid x_i) = e^{x_i'\beta_j} \Big/ \left(\sum_{l=1}^{J} e^{x_i'\beta_l} \right) \\ \beta_1 = 0 \end{cases} \qquad (6.36)$$

where, in addition to the definitions of x_i and β_j above,

ORM_i is the organization mode of i^{th} R&D project;

P_{ij} is the probability that the project *i* is governed by mode *j* , $j \in (1,2,...,J)$

The parameters β_j are estimated by maximizing a log likelihood function.[73]

B. Results and Analyses of the Multinomial Estimations (3 Alternatives)

Using the multinomial logit regression technique, 142 observations are employed to identify the factors underlying the choice between in-house, alliance and outsourcing.

As before, organizational mode (ORM) is the dependent variable, but it is now a polychotomous response variable which has three categories: in-house, alliance and outsourcing. When in-house is chosen as the organizational mode, ORM is set to 1; if alliance or outsourcing is chosen instead, it is set to 2 or 3 respectively. Among the 142 observations, 61 cases are organized by in-house, 58 by alliance and 23 by outsourcing. Accordingly, the shares for these three categories are 43.0%, 40.9% and 16.2%.

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[73] In this study, we use STATA 9.1 and GRETL to implement the estimation.

Table 6-4-1 reports the descriptive statistics of dependent variable and twelve explanatory variables for all the 142 observations[74]. Table 6-4-2 presents the correlation table of all the explanatory variables, and there isn't any worrying sign of strong correlation amongst the 12 explanatory variables.

Table 6- 4- 1: Descriptive Statistics for All Variables (Multinomial Analysis, 3 Alternatives)

Var.Code	Full Name	Mean (S.D.)				Min	Max
		Entire Samples (Num. of Obs.=142)	**In-house** (Num. of Obs.=61)	**Alliance** (Num. of Obs.=58)	**Outsourcing** (Num. of Obs.=23)		
Dependent Variable (In-house=1; Alliance=2; Outsourcing=3)							
ORM	Organization Mode					1	3
Independent Variables							
PS	Problem Structure	2.655 (0.826)	2.705 (0.803)	2.793 (0.833)	2.174 (0.717)	1	4
COM	Complexity	3.408 (0.764)	3.377 (0.778)	3.655 (0.690)	2.870 (0.626)	2	5
DEC	Decomposability	2.437 (0.803)	2.508 (0.744)	2.552 (0.820)	1.957 (0.767)	1	5
EKB	Existing Knowledge Base	3.592 (0.860)	4.049 (0.644)	3.379 (0.721)	2.913 (1.041)	1	5
COD	Codifiability	2.810 (0.825)	2.770 (0.864)	2.914 (0.801)	2.652 (0.775)	1	5
TEA	Teachability	2.592 (0.773)	2.574 (0.741)	2.690 (0.730)	2.391 (0.941)	1	5
SDK	Social Distribution of Knowledge	3.239 (1.038)	3.377 (0.916)	2.897 (1.003)	3.739 (1.176)	1	5
DU	Demand Uncertainty	2.408 (0.852)	2.410 (0.761)	2.431 (0.920)	2.348 (0.935)	1	5
HAS	Human Asset Specificity	1.415 (0.633)	1.443 (0.620)	1.431 (0.678)	1.304 (0.559)	1	4
PAS	Physical Asset Specificity	1.937 (0.755)	2.049 (0.784)	1.966 (0.772)	1.565 (0.507)	1	4
AP1	Appropriability1	3.085 (0.926)	3.115 (0.877)	3.000 (0.991)	3.217 (0.902)	1	5
AP2	Appropriability2	3.148 (0.663)	3.262 (0.705)	3.103 (0.640)	2.957 (0.562)	2	5

[74] In fact, this table is derived by merging the descriptive statistics tables of the three binary choice models (Table 11-3-1, 11-3-9, and 11-3-21), and calculating additionally the mean values for all the 142 observations. As we have discussed these three tables in the above text, we would not repeat our points.

Table 6- 4- 2: Correlation Table of the Explanatory Variables (Multinomial Analysis)

Num. of Obs.=142

			PS	COM	DEC	EKB	COD	TEA	SDK	DU	HAS	PAS	AP1	AP2
1	**Problem Structure**	PS	1											
2	**Complexity**	COM	0.472	1										
3	**Decomposability**	DEC	0.668	0.655	1									
4	**Existing Knowledge Base**	EKB	-0.200	-0.176	-0.305	1								
5	**Codifiability**	COD	0.299	0.428	0.405	-0.290	1							
6	**Teachablity**	TEA	0.455	0.296	0.403	-0.210	0.378	1						
7	**Social Distribution of Knowledge**	SDK	-0.077	-0.205	-0.118	-0.009	-0.029	-0.125	1					
8	**Demand Uncertainty**	DU	0.333	0.156	0.339	-0.148	0.000	0.083	-0.063	1				
9	**Human Asset Specificity**	HAS	0.005	0.175	0.101	-0.116	0.302	0.146	-0.131	0.091	1			
10	**Physical Asset Specificity**	PAS	0.135	0.291	0.397	-0.084	0.356	0.186	0.001	0.129	0.352	1		
11	**Appropriability1**	AP1	-0.425	-0.440	-0.412	0.293	-0.230	-0.308	0.053	-0.206	-0.169	-0.185	1	
12	**Appropriability2**	AP2	-0.101	-0.204	-0.136	0.206	-0.143	-0.089	-0.011	-0.032	0.022	-0.109	0.153	1

Table 6- 4- 3: Multinomial Logit Estimation Results (Model 4A)
(3 Alternatives, In-house vs. Alliance vs. Outsourcing)

Multinomial logistic regression	Number of obs = 142
Number of cases 'correctly predicted' = 99 (70%)	LR chi2(24) = 98.79
	Prob > chi2 = 0.0000
Log likelihood = -95.949	Pseudo R^2 = 0.340

	2(Alliance)						3(outsourcing)					
	Predicted Sign for Coef.	***Coef. (Std. Err.)***	***z***	***p-value***		***RRR (Std. Err.)***	***Predicted Sign for Coef.***	***Coef. (Std. Err.)***	***z***	***p-value***		***RRR (Std. Err.)***
const		8.787 (3.329)	2.64	0.008	***			18.394 (4.873)	3.77	0.000	***	
PS	-(?)	0.068 (0.419)	0.16	0.872		1.070 (0.449)	-	-0.854 (0.648)	-1.32	0.187		0.426 (0.276)
COM	+(?)	1.021 (0.460)	2.22	0.026	**	2.776 (1.277)	-	-0.831 (0.778)	-1.07	0.285		0.436 (0.339)
DEC	-	-1.255 (0.520)	-2.41	0.016	**	0.285 (0.148)	-	-0.828 (0.871)	-0.95	0.342		0.437 (0.381)
EKB	-	-1.986 (0.451)	-4.40	0.000	***	0.137 (0.062)	-	-2.915 (0.602)	-4.84	0.000	***	0.054 (0.033)
COD	-	-0.186 (0.349)	-0.53	0.595		0.830 (0.290)	-	0.124 (0.553)	0.22	0.823		1.132 (0.626)
TEA	-	0.130 (0.336)	0.39	0.699		1.139 (0.383)	-	-0.095 (0.556)	-0.17	0.865		0.910 (0.506)
SDK	-	-0.407 (0.230)	-1.77	0.076	*	0.666 (0.153)	-	0.317 (0.403)	0.79	0.431		1.374 (0.554)
DU	-	-0.059 (0.289)	-0.20	0.838		0.943 (0.273)	-	0.451 (0.494)	0.91	0.361		1.570 (0.775)
HAS	-	-0.447 (0.390)	-1.15	0.251		0.639 (0.249)	-	-0.330 (0.750)	-0.44	0.660		0.719 (0.539)
PAS	-	-0.078 (0.347)	-0.23	0.822		0.925 (0.321)	-	-1.384 (0.661)	-2.09	0.036	**	0.251 (0.166)
AP1	-	0.325 (0.284)	1.14	0.253		1.384 (0.394)	-	0.309 (0.509)	0.61	0.545		1.362 (0.694)
AP2	-	-0.197 (0.343)	-0.57	0.567		0.822 (0.282)	-	-0.887 (0.610)	-1.45	0.146		0.412 (0.251)

In-house (ORM==1) is the base outcome

*** $p<0.01$; ** $p<0.05$; * $p<0.1$

Table 6- 4- 4: Classification Table (Model 4A)

		Predicted			*Percentage Correct*
		1	2	3	
Actual	1	47	9	5	77.0%
	2	16	32	10	55.2%
	3	1	2	20	87.0%
Overall Percentage					70%

In model 4A, we include all the 12 explanatory variables for the estimation, in-house being the reference category. The results of the estimation are shown in Table 6-4-3.

As explained above, in the multinomial model, the coefficient should always be interpreted with reference to the base category. A direct interpretation of the estimated coefficient is given by (6.29),

$$\frac{\partial ln(P_{ij} / P_{i1})}{\partial x_{ik}} = \beta_{jk}$$

when category 1 is set as the reference ($\beta_1 = 0$) and β_{jk} is variable x_k*'s* coefficient for alternative j.

A positive (negative) parameter β_{jk} therefore means a higher value for explanatory variable x_k increase (decrease) the relative probability of choosing alternative j over alternative 1(reference category).

In addition to coefficients (β_{jk}), the estimation results can also be reported as ***relative risk ratios*** (RRR), i.e. exp(β_{jk}),which gives the precentage change in the probability of choosing alternative j (versus base category) associated with an one-unit change in the explanatory variable. Figures greater than (less than) one indicate a higher(lower) relative probability of choosing alternative j over the baseline alternative if the explanatory variable increases by one unit. Intuitively, $\beta_{jk} > 0$ is equivalent to $\exp(\beta_{jk}) > 1$, so $\exp(\beta_{jk}) > 1$ carries the same meaning as that of $\beta_{jk} > 0$. More technically, as given by (6.25), for individual *i*, the odds ratio of alternative j versus baseline alternative (1) is:

$$\frac{P_{ij}}{P_{i1}} = \frac{e^{x_i'\beta_j} \Big/ \left(1+\sum_{l=2}^{J} e^{x_i'\beta_l}\right)}{1 \Big/ \left(1+\sum_{l=2}^{J} e^{x_i'\beta_l}\right)} = e^{x_i'\beta_j} \tag{6.37}$$

Thus, holding all other variables constant, for a one unit increase in x_{ik}, the odds of choosing alternative j over 1 changes by a factor of exp (β_{jk}). In other words, a one unit increase for an individual's score in k^{th} explanatory variable makes it exp (β_{jk}) times more likely to choose alternative j over 1, or equivalently, increases the likelihood of choosing alternative j over the baseline alternative by $100\left[\exp(\beta_{jk})-1\right]$%.

Having clarified the meaning of the coefficient, the interpretations of the estimation results become straightforward.

Alliance

For the alternative of alliance, 9 of the 12 coefficients for the explanatory variables bear the right sign as predicted by the theory, 4 of which are significant at the level of 10% or higher, and all these 4 variables are KBV variables.

The coefficient of EKB is negative and highly significant (at the level of 1%), suggesting that a higher EKB value decreases the relative probability of choosing alliance over internal organization. To be more exact, the RRR for EKB is 0.137, indicating that a one unit increase in EKB reduces the likelihood of choosing alliance over in-house by 86.3%. To put this plainly, the result suggests, as a firm has increasingly more complete knowledge that is required to solve a problem, it is more likely that the problem-solving will be organized in-house rather than by alliance.

The coefficient for COM and DEC are both significant at the level of 5%.

The positive sign of COM's coefficient implies that an increase in the COM adds to the relative probability of choosing alliance over in-house. The RRR for COM further indicates that the magnitude of this effect is so large that a one unit increase in COM makes it 2.776 times more likely to choose alliance over in-house. In short, the results suggest, *ceteris paribus*, alliance is more preferred than in-house for solving more complex problem.

The coefficient for DEC, on the other hand, bears a negative sign, suggesting that a higher DEC value reduces the chance that alliance be chosen over in-house. The magnitude of this effect, as measured by RRR, is 0.285, meaning that a one unit increase in DEC decreases the chance of choosing alliance over in-house by 72.5%. In a nutshell, the results indicate that compared with alliance, in-house is more preferable for solving non-decomposable problem.

The coefficient for SDK is also significant, but only at a marginal level of 10%. The negative sign for this coefficient suggests, as the value of SDK increases, the relative probability of choosing alliance over in-house becomes lower. The RRR for SDK (0.666) further confirms that a one unit increase in SDK decreases the chance of choosing alliance over in-house by one third. Overall, the implication is: R&D projects involving a higher degree of socially distributed knowledge are more likely to be organized internally rather than by alliance.

Outsourcing

As for the alternative of outsourcing, 8 of the 12 explanatory variables carry a theoretically consistent sign for its coefficient; however, only two of them are significant at the level of 10% or higher.

Again, the coefficient for EKB is significant at the level of 1%. Its negative sign suggests that a higher EKB value decreases the relative probability of choosing outsourcing over internal organization. The RRR for EKB (0.054) indicates that the effect is so strong that a one unit increase in EKB decreases the likelihood of choosing outsourcing over in-house by 94.6%. In brief, the results reveal that a higher level of existing knowledge base favours the choice of in-house over outsourcing[75].

[75] In fact, using the multinomial estimation results, we can infer the effect of a variable on the binomial choice between two non-base categories (to be more exact, we can calculate the coefficients of a binomial logit models for the choice between two non-base alternatives). Specifically, from 11.20 and 11.31, we have

$$ln\left(\frac{P_{ij}}{P_{im}}\right) = \ln\left(\frac{Prob[y_i = j \mid y_i = j \ or \ m]}{1 - Prob[y_i = j \mid y_i = j \ or \ m]}\right) = \ln \Omega_{j|m}(x_i)$$

$$= x_i'(\beta_j - \beta_m) = x_i'\beta_{j|m}$$

This implies, $\beta_j - \beta_m = \beta_{j|m}$, where β_j , β_m are the coefficient vectors for alternative *j* and *m* respectively in the multinomial model, and $\beta_{j|m}$ is the coefficient vector of the binomial logit model for the choice between alternative *j* and *m* (m being the base).
Taking derivative of the above equation with respect to the k^{th} explanatory variables x_k . We have

$$\frac{\partial ln(P_{ij} / P_{im})}{\partial x_{ik}} = \beta_{jk} - \beta_{mk} = \frac{\partial ln \ \Omega_{j|m}(x_i)}{\partial x_{ik}} = \beta_{jk|m}$$

PAS is the only TCE variable that turns out to be significant in the estimation. A negative coefficient of PAS for the alternative of outsourcing indicates that a higher PAS value discourages the choice of outsourcing over in-house. More accurately, the RRR for PAS is 0.251, suggesting that a one point increase in PAS reduces the relative chance of choosing outsourcing over in-house by 75%. The message behind the results is clear—as the physical assets invested to support a R&D project tend to be more specific, it is more likely that the project will be organized internally rather than by outsourcing.

Summing up, model 4A seems to fit the data reasonable well. Most notably, of the 142 observations, it correctly predicts the organizational mode for 99 cases (see Table 6-4-4), which yields a "hit rate" of 70 %, a level much higher than random prediction (33.33%), or if all observations were assigned to the most frequently observed alternative (42.96%). However, we note that "hit rate" is sort of unbalanced. Specifically, for the alternative of in-house and outsourcing, the "hit" is fairly accurate (77% and 87% respectively), but for the alternative of alliance, the figure is obviously lower (55.2%).

In addition, we note that, with no surprise, the estimation results of the multinomial logit model are fairly similar to those of the three probit models. For example, in the current model, for the alternative of alliance, 10 coefficients for the explanatory variables show up with the right sign, 4 of which are estimated to be significant; while in the probit model of 1A, exactly the same 10 variables bear a theoretically consistent sign, and exactly the same 4 variables are found to be significant for the choice of in-house vs. alliance. In other words, the results for the multinomial logit estimation seem to carry roughly the same messages as that in the first stage probit estimations. That being said, we also note that, compared with the results of first

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where β_{jk} , β_{mk} are the coefficient of the k^{th} explanatory variables x_k under alternative j and m respectively in the multinomial model, and $\beta_{jk|m}$ is the coefficient of the k^{th} explanatory variables in the binomial logit model for the choice between alternative j and m (m being the base).
For example, in our case, EKB's coefficient for the alternative of alliance is -1.986; and for the alternative of outsourcing, it is -2.915. Using the above results, it could be inferred that the EKB's coefficient in the binomial logit model for the choice between alliance and outsourcing (outsourcing being the base) would be 0.929 (In fact, the coefficient estimated from this binomial logit model is 0.979. Note that there is a slight difference between these two figures, since the binomial logit model is estimated with smaller samples, so the equation $\beta_{jk} - \beta_{mk} = \beta_{jk|m}$ would not hold exactly). Moreover, as

$$\frac{\partial ln\ \Omega_{j|m}(x_i)}{\partial x_{ik}} = \beta_{jk|m},$$

it could also be concluded that a higher EKB increases the relative probability of choosing alliance over outsourcing.

stage estimations[76], fewer variables are estimated to be significant in the multinomial logit models[77]. For example, in model 2A, 4 coefficients of the 12 explanatory variables are estimated to be significant for the choice between in-house and outsourcing; while in the current model, under the alternative of outsourcing (in-house being the baseline category), only two variables pass the significance test.

To conclude for the above discussions, the MNL model performs reasonably well, and the estimation results are basically consistent with the results of first stage binomial probit analyses. Specifically, hypotheses from both theoretical approaches receive some support from the data. On the KBV side, the effects of EKB are persistent and highly significant (at the level of 1%), the effects of COM and DEC are significant at the level of 5%, but only for the choice between in-house and alliance. On the TCE side, PAS is the only variable estimated to be significant (at the level of 5%), but only for the choice between in-house and outsourcing. Overall, it seems fair to maintain that the three-category MNL estimation results lend relatively more supports to KBV than TCE. Furthermore, compared with the results of first stage estimations, the weight of the evidence in favour of KBV is basically the same, while that for TCE tends to be weaker.

As illustrated above, the coefficients of the variables for non-base category should always be interpreted with reference to the baseline category, but the probability of choosing the baseline category is itself a variable. Therefore, we still don't know how the change in a variable might affect the ***absolute*** possibility of choosing a specific outcome. In this regard, checking the marginal effects of each variable would provide additional information.

In order to filter out noise and to improve the accuracy for calculating the marginal effects, it is desirable to simplify the model specification by dropping highly insignificant variables.

As there is no well-accepted model selection procedure for the multinomial logit model (MNL)[78], we arbitrarily set the following criteria for simplifying our models.

[76] The author is aware that it is less consistent to compare the results of the MNL with that of a binary probit, although in most cases the two results are highly compatible. A more appropriate practice is to compare the results of the MNL with that of the binomial logit. In fact, we have done so, and the estimation results of the binary logit (in-house vs. outsourcing) turn up with three significant variables, namely EKB, PAS and DEC, and AP2 is on the verge of significance (p=0.109) (cf. table A-6-1 & A-6-2 in Appendix II). Given these, we believe our conclusion below is essentially sound.

[77] This happens probably because the multinomial model imposes additional constraints.

[78] There are some statistical procedures for the elimination of insignificant variables (by setting threshold *p*-value), but the selection of model specification is more than a matter of applying some pre-set statistical criteria in a mechanical way. Without careful consideration of the substantive issue

Specifically, variables would be dropped if:

1. the *p*-value of its coefficient is greater than 0.20 for all the alternatives, and at the same time;
2. the sign of its coefficient is inconsistent with theoretic prediction for at least one of the alternatives.

By these criteria we pick up COD, TEA, DU and AP1.

We then test for the joint omission of these four variables, the null hypothesis being that

H_0: *In model 4A, all regression parameters are zero for the variables of COD, TEA, DU and AP1.*

The likelihood ratio test comes up with a Chi2(8)= 3.115 with p-value=0.927, suggesting that the null hypothesis can't be rejected and the parameters for the above four variables could all be safely assumed as zero and be dropped from regression model.

We then estimate the new model (4B), the results are presented in Table 6-4-5.

related to the research, researchers are not encouraged to delete variables (Hausman & McFadden, 1984; Jeremy & Long, 2001).

Table 6- 4- 5: Multinomial Logit Estimation Results (Model 4B)
(In-house vs. Alliance vs. Outsourcing)

Multinomial logistic regression	Number of obs = 142
Number of cases 'correctly predicted' = 99 (70%)	LR chi2(16) = 95.67
	Prob > chi2 = 0.0000
Log likelihood = -97.506	Pseudo R^2 = 0.329

	2 (Alliance)						3 (Outsourcing)					
	Predicted Sign for Coef.	*Coef. (Std. Err.)*	*z*	*p-value*		*RRR (Std. Err.)*	*Predicted Sign for Coef.*	*Coef. (Std. Err.)*	*z*	*p-value*		*RRR (Std. Err.)*
const		9.974 (2.927)	3.41	0.001	***			19.805 (4.167)	4.75	0.000	***	
PS	-(?)	-0.024 (0.379)	-0.06	0.949		0.976 (0.370)	-	-0.891 (0.597)	-1.49	0.135		0.410 (0.245)
COM	+(?)	0.855 (0.419)	2.04	0.041	**	2.352 (0.984)	-	-0.982 (0.710)	-1.38	0.167		0.374 (0.266)
DEC	-	-1.250 (0.510)	-2.45	0.014	**	0.286 (0.146)	-	-0.667 (0.808)	-0.82	0.409		0.513 (0.415)
EKB	-	-1.865 (0.425)	-4.39	0.000	***	0.155 (0.066)	-	-2.723 (0.560)	-4.86	0.000	***	0.066 (0.037)
SDK	-	-0.407 (0.225)	-1.81	0.070	*	0.665 (0.150)	-	0.289 (0.382)	0.76	0.449		1.335 (0.510)
HAS	-	-0.499 (0.370)	-1.35	0.178		0.607 (0.225)	-	-0.099 (0.667)	-0.15	0.883		0.906 (0.605)
PAS	-	-0.127 (0.339)	-0.38	0.708		0.881 (0.298)	-	-1.303 (0.645)	-2.02	0.043	**	0.272 (0.175)
AP2	-	-0.191 (0.342)	-0.56	0.576		0.826 (0.282)	-	-0.900 (0.588)	-1.53	0.126		0.406 (0.239)

In-house (ORM==1) is the base outcome

*** $p<0.01$; ** $p<0.05$; * $p<0.1$

Table 6- 4- 6: Classification Table (Model 4B)

		Predicted			*Percentage Correct*
		1	2	3	
Actual	1	47	10	4	77.0%
	2	16	33	9	56.9%
	3	1	3	19	82.6%
Overall Percentage					70%

It turns out that the estimation results of the new model are structurally similar to those of model 4A. Specifically, under corresponding alternatives, the same sets of variables are estimated to be significant at exactly the same level of significance. This means, even with the 4 variables deleted, the new model performs roughly as well as the old one. This assertion can be further confirmed by observing that the overall "hit rate" of the new model is maintained at the same level as that of model 4A (see table 6-4-6)[79], and the Pseudo R^2, an indictor of goodness of fit, drops only by 0.011 (Pseudo R^2 for model 4A is 0.340, whereas for model 4B is 0.329). Finally, it is also worth noting that with those highly insignificant variables being dropped; in the new model (4B), only one variable bears a theoretically inconsistent sign.

Marginal Effects

Based on model 4B, we calculated the marginal effects of the 8 explanatory variables using (6.27), (6.23), (6.24) and the estimated parameters. Table 6-4-7 exhibits the marginal effects of the 8 explanatory variables at sample means. The effects of the point-by-point increase of each explanatory variable on the predicted probability of each alternative are presented in table 6-4-8.

[79] We note that the "hit rate" of the new model is still quite unbalanced.

Table 6- 4- 7: Marginal effects at Sample Means (Model 4B)

	1 (In-house) $y=Pr(ORM=1 \mid x=\overline{X})=0.419$				2 (Alliance) $y=Pr(ORM=2 \mid x=\overline{X})=0.517$				3 (Outsourcing) $y=Pr(ORM=3 \mid x=\overline{X})=0.064$			
VAR	*dy/dx (Std. Err)*	*z*	*p-value*		*dy/dx (Std. Err)*	*z*	*p-value*		*dy/dx (Std. Err)*	*z*	*p-value*	
PS	0.029 (0.090)	0.33	0.744		0.024 (0.088)	0.27	0.789		-0.053 (0.035)	-1.52	0.128	
COM	-0.159 (0.099)	-1.61	0.107		0.246 (0.099)	2.48	0.013	**	-0.088 (0.043)	-2.06	0.040	**
DEC	0.289 (0.120)	2.40	0.016	**	-0.290 (0.118)	-2.46	0.014	**	0.001 (0.044)	0.03	0.974	
EKB	0.477 (0.097)	4.90	0.000	***	-0.375 (0.094)	-3.99	0.000	***	-0.102 (0.041)	-2.48	0.013	**
SDK	0.080 (0.054)	1.50	0.134		-0.111 (0.053)	-2.10	0.035	**	0.031 (0.022)	1.39	0.164	
HAS	0.111 (0.088)	1.26	0.207		-0.121 (0.087)	-1.40	0.162		0.011 (0.037)	0.29	0.773	
PAS	0.063 (0.081)	0.78	0.438		0.012 (0.080)	0.15	0.884		-0.074 (0.037)	-2.03	0.042	**
AP2	0.066 (0.081)	0.81	0.417		-0.018 (0.080)	-0.22	0.826		-0.048 (0.035)	-1.38	0.167	

*** p<0.01; ** p<0.05; * p<0.1

Before turning to a detailed discussion of the marginal effects, it should be reminded that at any given point, the marginal effects of a variable for the three different alternatives sum up to zero. This property follows from the fact that the probabilities of all the alternatives add to one. Intuitively, if the change of a variable adds to the probability of choosing a specific alternative, it must reduce the probability of choosing some other alternative(s).

As shown in table 6-4-7, at sample means, the marginal effects of EKB are both the strongest and the most significant among all the explanatory variables, and the effects manifest themselves persistently for all the three alternatives. Specifically, at this point, a one-unit increase in EKB adds to the probability of choosing in-house by 47.7% (significant at the level of 1%); at the same time, it reduces the chance of choosing alliance and outsource by 37.5% (significant at the level of 1%) and 10.2% (significant at the level of 5%) respectively.

Apart from EKB, the marginal effects of COM are persistently significant as well, but with a smaller magnitude. At sample means, a one-unit increase in COM improves the chance of choosing alliance by 24.6% (significant at a level of 5%);

meanwhile, it reduces the probability of choosing the other two alternatives. For outsourcing, a one-unit increase in COM make it 8.8% less likely to be chosen (significant at a level of 5%), and for in-house, the figure is 15.9% (on the verge of significance, p=0.107).

The marginal effects for DEC are significant for two of the alternatives, both at the level of 5%. At sample means, a one-point increase in DEC increases the probability of choosing in-house by 28.9%. This comes almost exclusively via a reduction in the probability of choosing alliance, and it has virtually no effect on outsourcing.

The marginal effects of SDK and PAS are significant for only one of the alternative. For SDK, a one-point increase at sample means makes it 11.1% less likely to choose alliance (significant at the level of 5%), at the same time, it increases the chance of choosing the other two alternatives, but these effects are not significant enough. For PAS, a one-point increase makes it 7.4% less likely to choose outsourcing (significant at the level of 5%). This comes mainly via the increase in probability of choosing in-house, but the effect is far from being significant.

As for all other variables, we note that although their marginal effects are not significant; the directions (signs) of their effects are mostly consistent with the predictions of theory. In particular, the marginal effects of PS are of some interest. At samples means, a unitary increase in PS make it 5.3% less likely to choose outsourcing (p=0.128), at the same time, it increases the chance of choosing the other two alternative by roughly the same magnitude, but the effects are not significant.

All the above marginal effects are evaluated at the sample means. As has been pointed out above, the marginal effect for a given variable varies continuously over the sample space. At two different points, both the magnitude and the sign of the marginal effect for the same variable could be different, and there is no guarantee that the mean-point marginal effect is representative enough. To evaluate the "overall" marginal effect, an exposition of how the predicted probability of each alternative is affected by the point-by-point increase of each variable would be helpful. Based on model 4B, we calculate the marginal effects of each variable on a point-by-point incremental basis[80], and the results are presented in table 6-4-8 and graphically as Figure 6-4-1 to Figure 6-4-5.

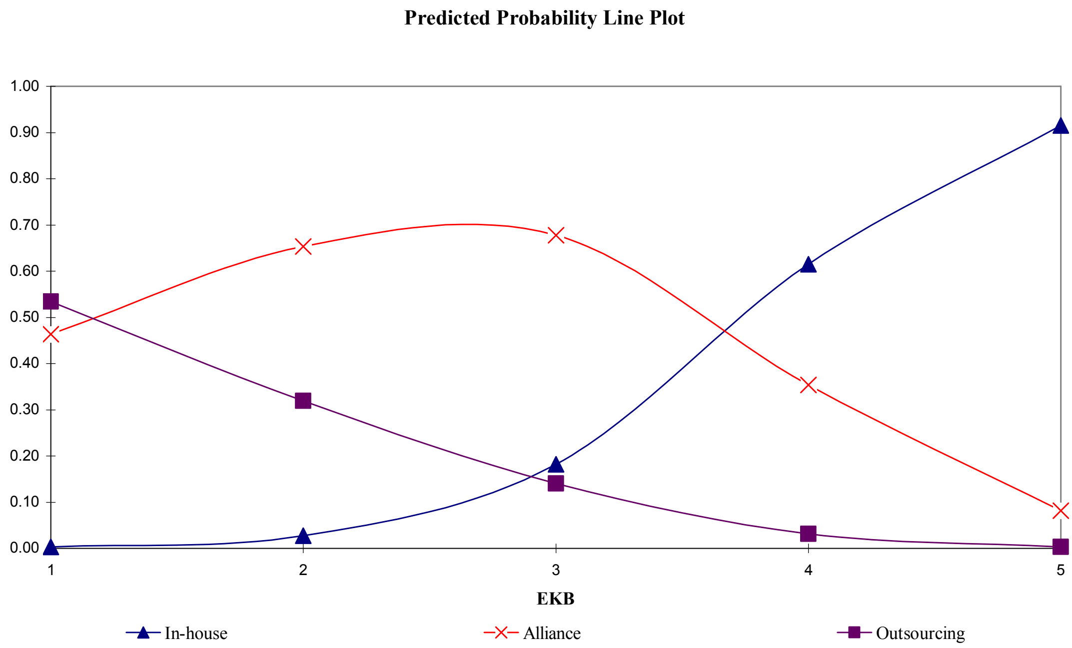
[80] To be more exact, the "marginal effect" is the difference of the predicted probabilities for an alternative when the value of an explanatory variable takes two consecutive integers, holding all other explanatory variables constant at their means.

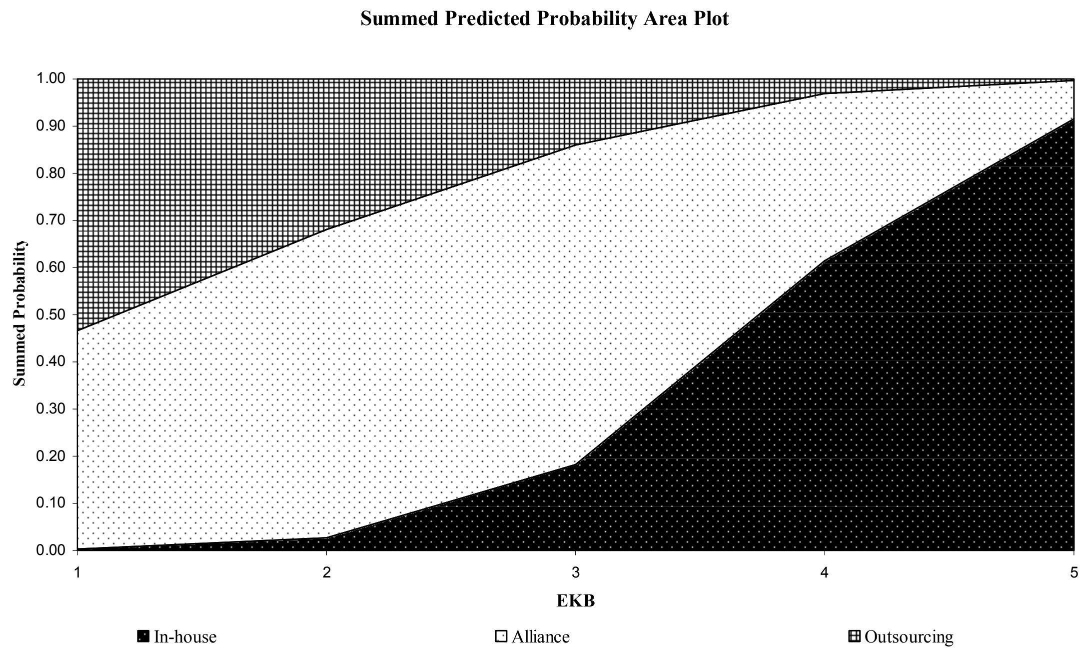
Table 6- 4- 8: The Effects of the Point-by-Point Increase of Each Explanatory Variable on the Predicted Probability of Each Alternative (Model 4B) ‡

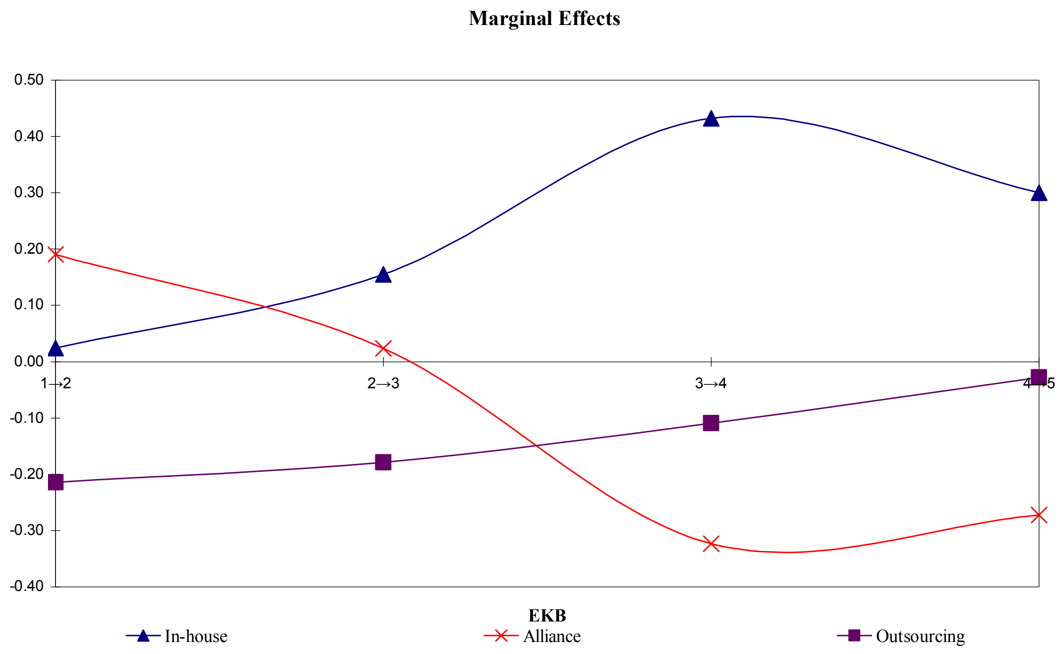
		1	2	3	4	5
Significant Variables						
COM	In-house	0.358	0.504	0.476	0.319	0.171
	Alliance	0.056	0.187	0.414	0.653	0.823
	Outsource	0.586	0.309	0.109	0.027	0.006
DEC	In-house	0.113	0.300	0.583	0.814	0.928
	Alliance	0.841	0.638	0.355	0.142	0.046
	Outsource	0.045	0.062	0.062	0.044	0.026
EKB	In-house	0.003	0.027	0.182	0.615	0.915
	Alliance	0.463	0.654	0.677	0.354	0.082
	Outsource	0.534	0.319	0.140	0.031	0.003
SDK	In-house	0.241	0.317	0.400	0.477	0.538
	Alliance	0.740	0.648	0.543	0.432	0.324
	Outsource	0.019	0.034	0.057	0.091	0.138
PAS	In-house	0.344	0.423	0.473	0.510	0.544
	Alliance	0.477	0.517	0.509	0.484	0.454
	Outsource	0.179	0.060	0.018	0.005	0.002
Other Variables						
PS	In-house	0.338	0.395	0.428	0.446	0.458
	Alliance	0.434	0.496	0.524	0.533	0.533
	Outsource	0.227	0.109	0.048	0.021	0.009
HAS	In-house	0.374	0.484	0.591	0.685	0.761
	Alliance	0.567	0.446	0.331	0.233	0.157
	Outsource	0.060	0.070	0.078	0.082	0.082
AP2	In-house	0.255	0.337	0.409	0.472	0.528
	Alliance	0.474	0.517	0.519	0.495	0.457
	Outsource	0.271	0.146	0.072	0.034	0.015

‡ When calculating the effect of a variable, other variables are held constant at their sample means.

Figure 6- 4- 1: The Effects of the Point-by-Point Increase of EKB on the Predicted Probability of Each Alternative (Model 4B)

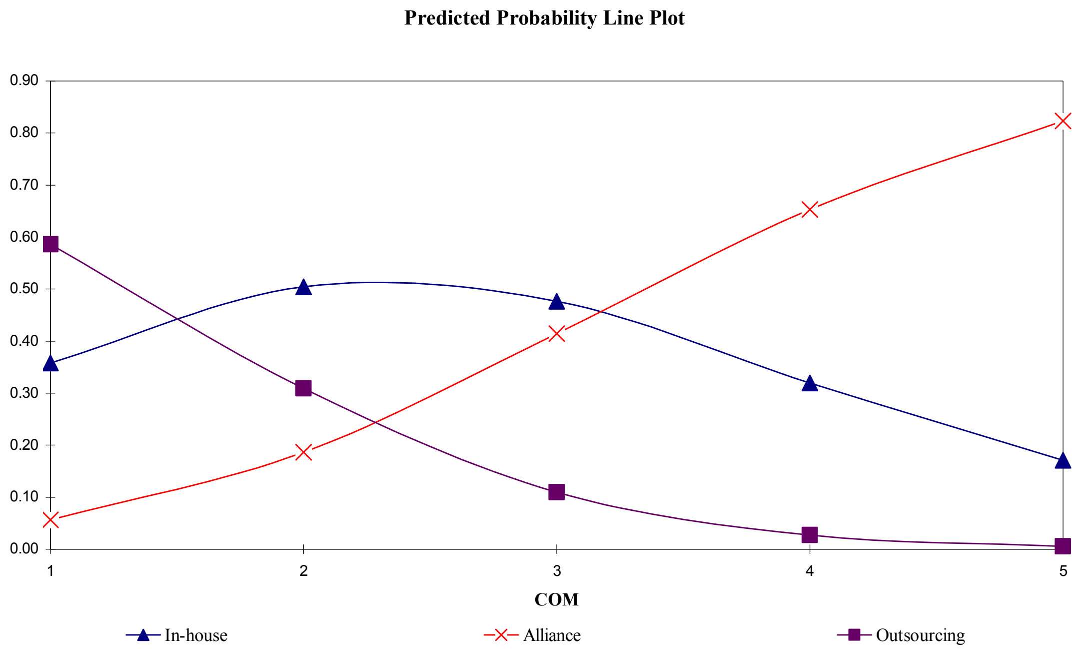


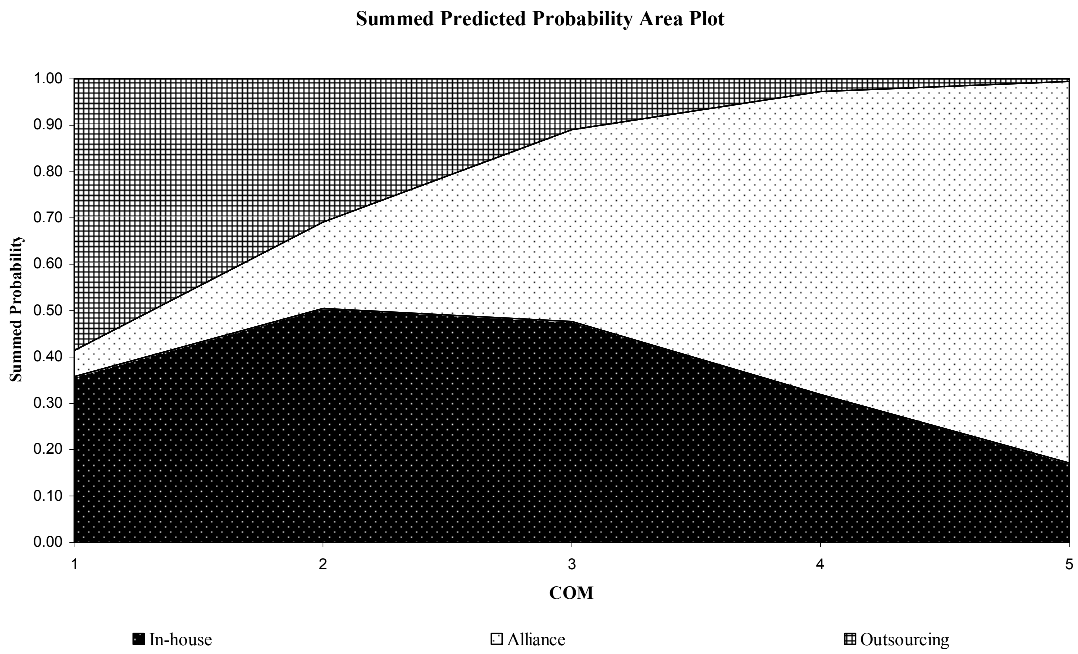


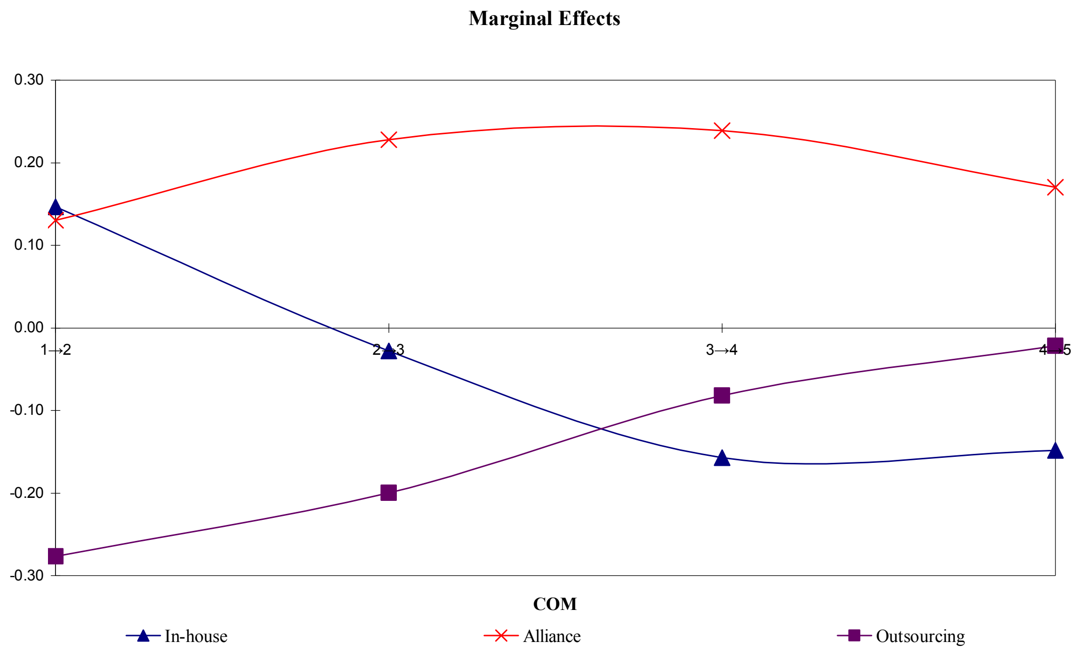


As EKB varies from 1 to 5 (holding all other explanatory variables constant at their sample means), the probability of choosing in-house increases monotonically, while the probability of choosing outsourcing, on the contrary, drops steadily. The effect on alliance is non-monotonic. At lower value of EKB, the increase of EKB increases the odds that alliance be chosen (positive marginal effect), but at higher value range of EKB, it reduces the odds instead (negative marginal effect). In short, the message is, at lowest value of EKB, outsourcing and alliance are more preferred and in-house is least likely to be chosen; while in the medium range of EKB, alliance is a best choice; and for higher value of EKB, internal organization is unambiguously the first option.

Figure 6- 4- 2: The Effects of the Point-by-Point Increase of COM on the Predicted Probability of Each Alternative (Model 4B)



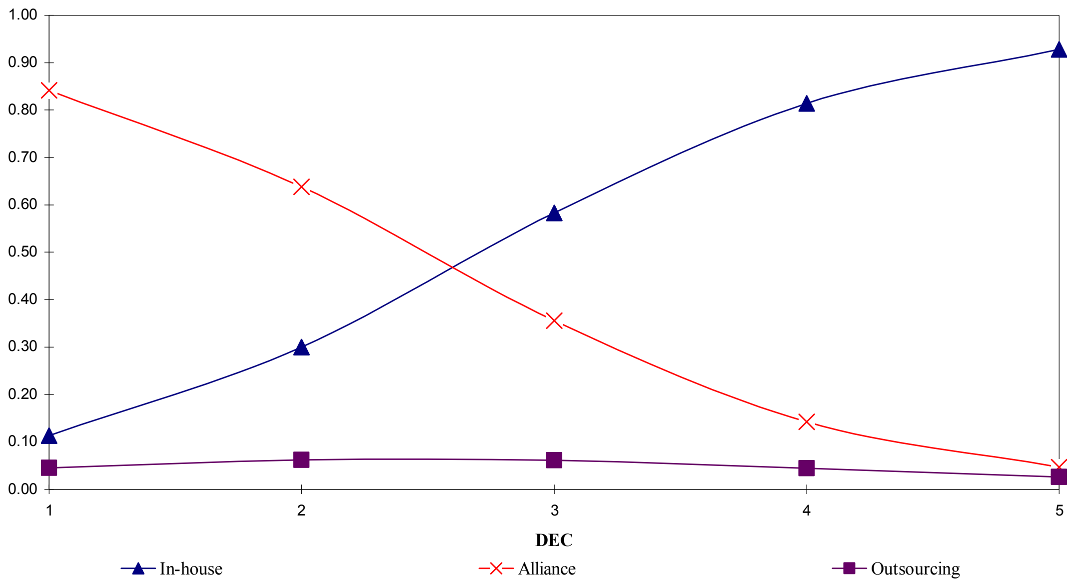




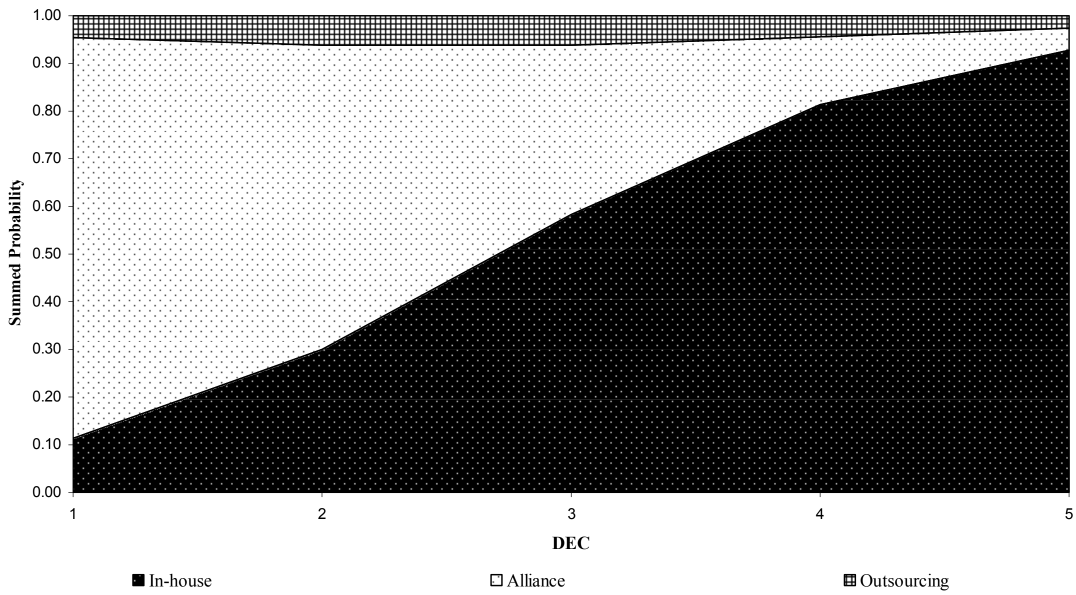
As COM increases from 1 to 5, the probability of choosing alliance increases steadily, while the probability of choosing outsourcing moves in the opposite direction. Its impact on in-house is non-monotonic. At lower value range, the increase in COM value adds to the probability of choosing in-house, after that, it reduces the odds instead. Overall, the message is, for problem of lowest complexity, outsourcing is the most preferable choice; for problem of medium-complexity, in-house is more likely to be chosen; while for highly complex problem, alliance is the first option.

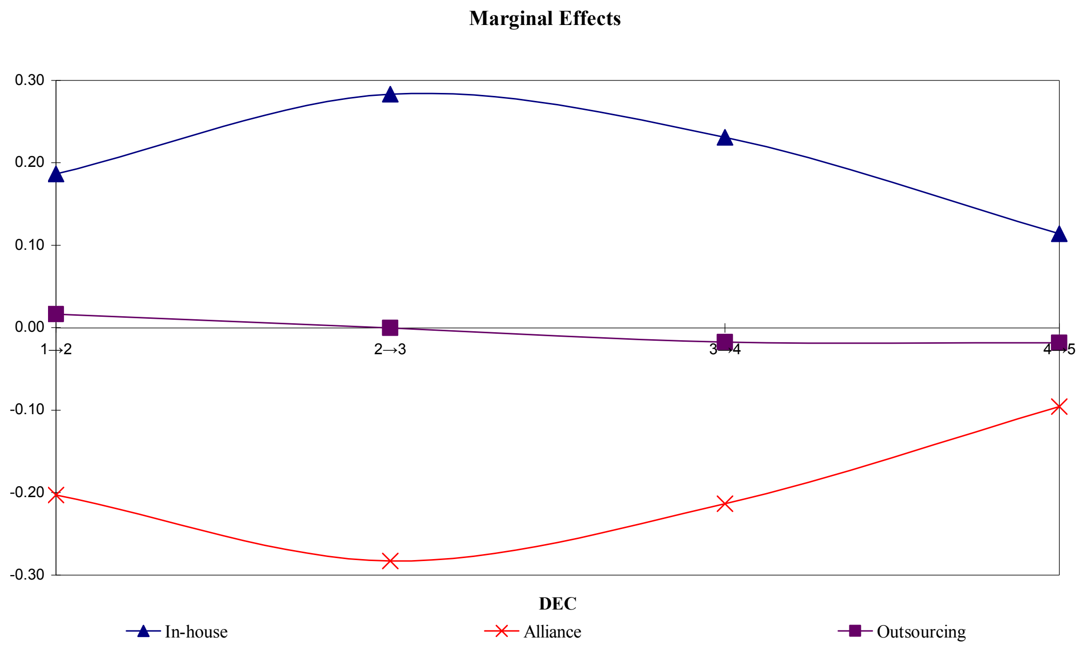
Figure 6- 4- 3: The Effects of the Point-by-Point Increase of DEC on the Predicted Probability of Each Alternative (Model 4B)

Predicted Probability Line Plot



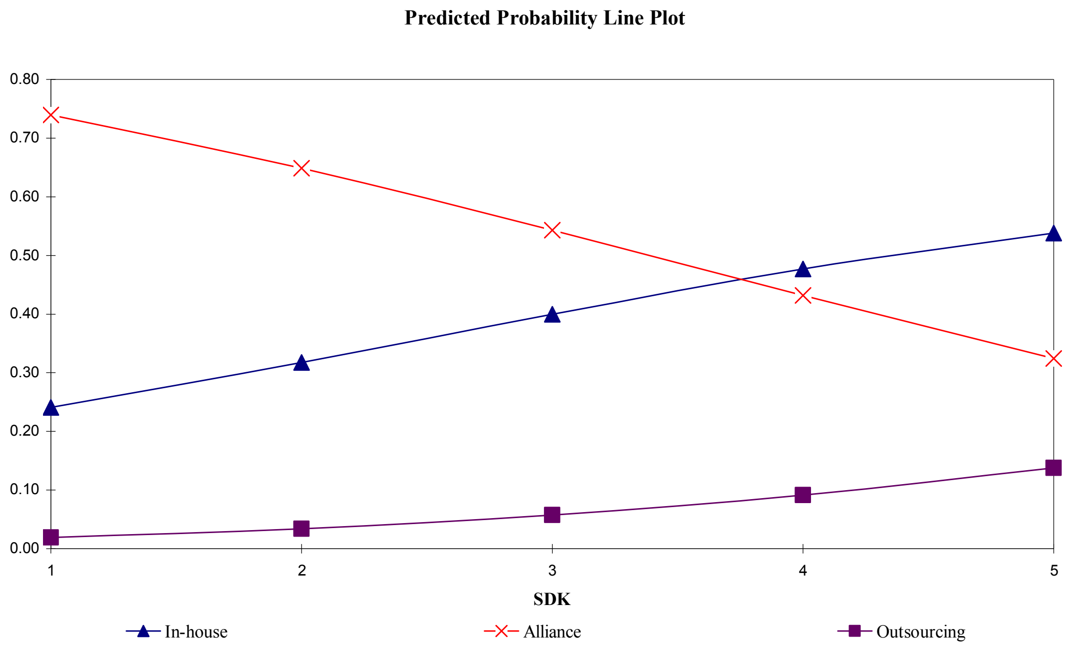
Summed Predicted Probability Area Plot

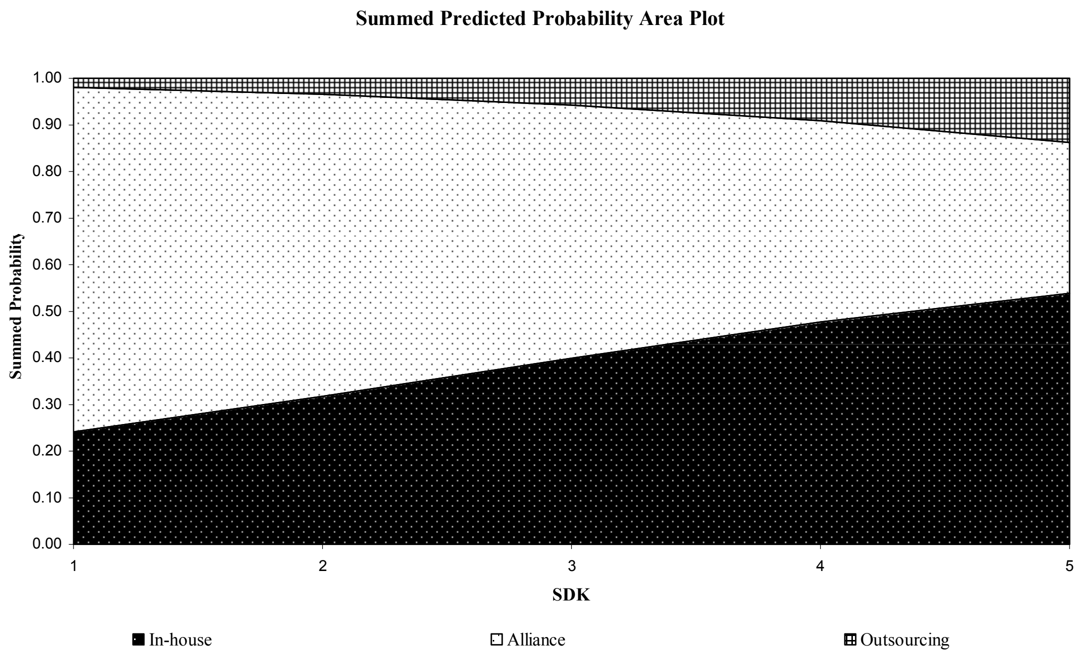


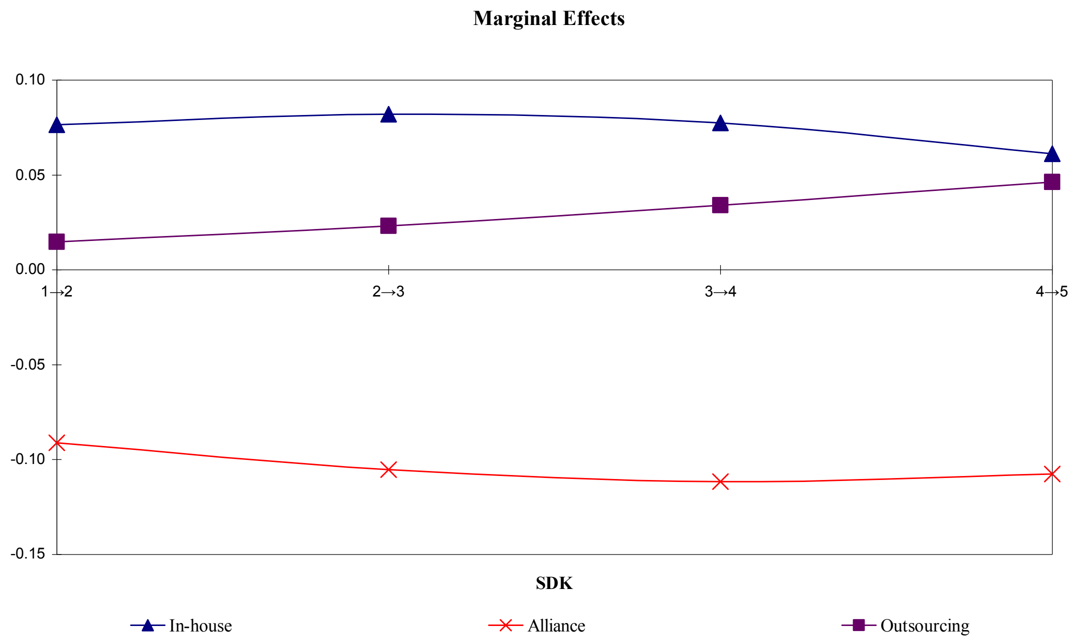


The effects of DEC on the probability of choosing any of the three alternatives are basically linear. Specifically, an increase in DEC adds to the probability of choosing in-house, and this comes almost exclusively via a reduction in the probability of choosing alliance. Meanwhile, DEC seems to have very little impact on the probability of choosing outsourcing, since this probability is rather stable and small with respect to DEC. Overall, the figures suggest, *ceteris paribus*, for easily decomposable problem, alliance is more likely to be chosen, while for non-decomposable problem, in-house is the best choice.

Figure 6- 4- 4: The Effects of the Point-by-Point Increase of SDK on the Predicted Probability of Each Alternative (Model 4B)

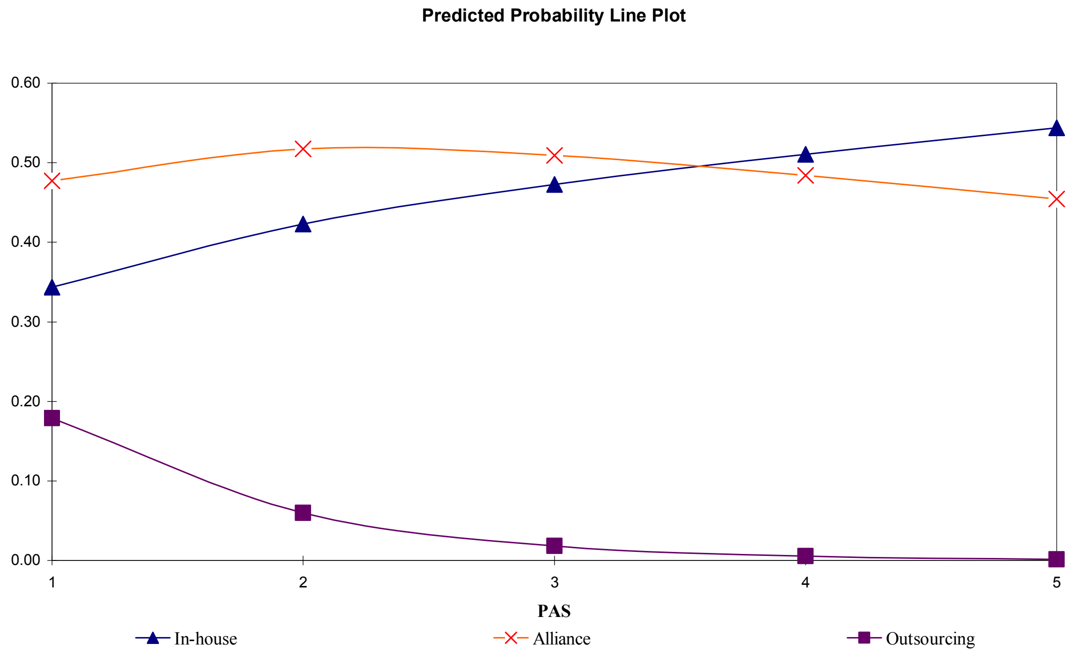


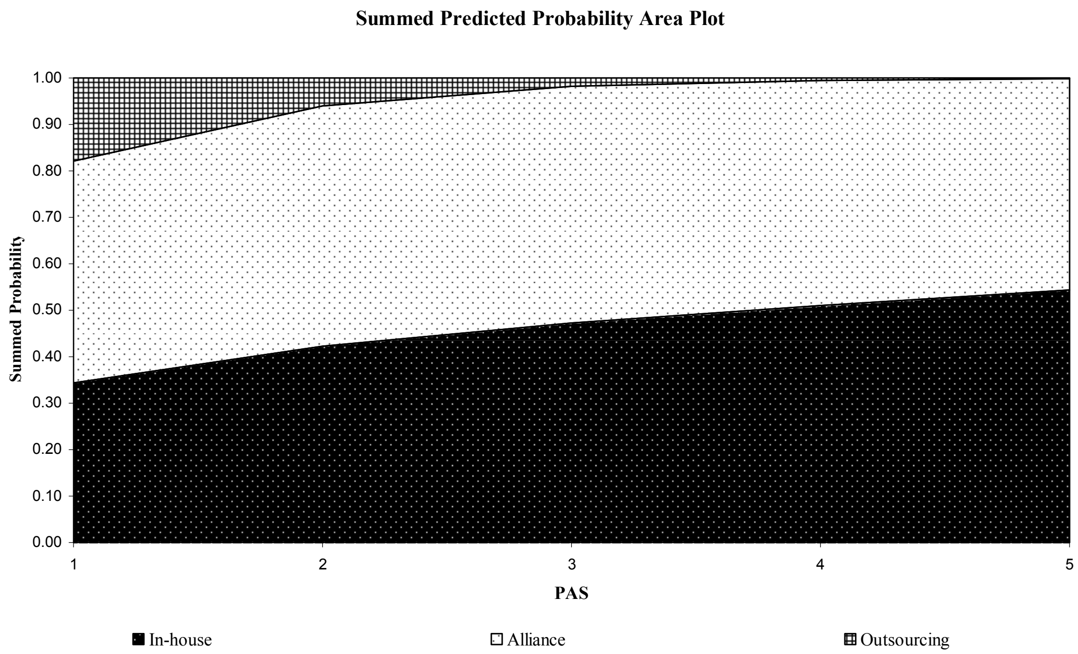


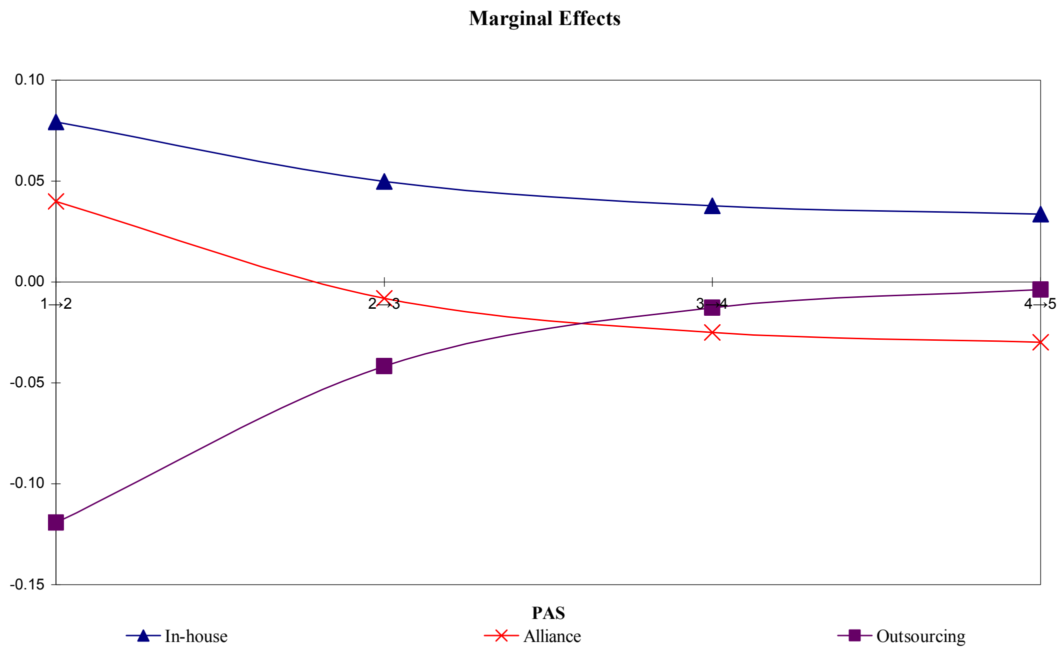


The effects of SDK on the probability of choosing any of the three alternatives are approximately linear as well. Specifically, each one-point increase of SDK adds to the probability of choosing in-house by 7% or so. At the same time, it decreases the probability of choosing alliance by roughly 10%, and its impact on outsourcing is much smaller. In a nutshell, the message is: if a R&D project involves highly socially distributed knowledge (as indicated by a high value of SDK), it is most likely to be organized in-house; otherwise (i.e., when SDK value is low or medium), alliance is the favoured choice; and finally, the change of SDK has very little impact on the choice of outsourcing.

Figure 6- 4- 5: The Effects of the Point-by-Point Increase of PAS on the Predicted Probability of Each Alternative (Model 4B)







As shown in the figures, a higher PAS value lower the probability of choosing outsourcing, at the same time, it adds to the probability of choosing in-house. The line plot for the predicted probability for choosing alliance is nearly horizontal; with the figures fluctuating narrowly at around 45%. Summing up, as PAS increase, it is more likely that in-house will be chosen, and this comes mainly via the reduction in the probability of choosing outsourcing.

Diagnostics and Testing

To check model specification and to assess the validity of the estimation results, the multinomial logit regression often requires some quality assessment tests (Cheng & Long, 2007; Freese & Long, 2001; Hausman & McFadden, 1984; Long & Freese, 2006; McFadden, Train, & Tye, 1977). As a final step, we conduct some diagnostic testing on the above three-category multinomial estimation results.

Firstly, we want to see whether some categories of the dependent variable could be combined—for example, whether it makes sense to combine "alliance" and "outsourcing", since in practice, it is sometimes difficult to perfectly differentiate certain types of outsourcing (such as ODM) from the contract-based alliance (H. Chen & Chen, 2003).

From an econometric point of view, outcomes (categories) should be combined and treated as identical if their coefficients do not differ from each other (J. A. Anderson, 1984; Long & Freese, 2006). Put differently, we can pool together certain categories of the dependent variable if all our explanatory variables jointly do not differentiate between them.

We then conduct the LR (likelihood-ratio) tests and Wald tests for combining outcome categories. The null hypothesis being that[81]:

H₀: *The differences of all coefficients (except intercepts) associated with given pair of outcomes are 0, i.e.,* $(\beta_{1,\ m|Base} - \beta_{1,\ n|Base}) = \cdots = (\beta_{K,\ m|Base} - \beta_{K,\ n|Base}) = 0$, *where K is the number of explanatory variables (not including constant) in the model, and* $\beta_{k,m|Base}$ *is the coefficient for* x_k *under outcome m when Base is set as the reference category (in this case, categories can be collapsed).*

The results of the two tests are given as follows (Table 6-4-9):

Table 6- 4- 9: Results of LR and Wald Tests for Combining Outcome Categories (Model 4B)

LR Tests			
Categories tested	**chi2**	**df**	**P>chi2**
2-3	39.646	8	0.000
2-1	41.462	8	0.000
3-1	67.749	8	0.000
Wald Test			
Categories tested	**chi2**	**df**	**P>chi2**
2-3	20.443	8	0.009
2-1	26.008	8	0.001
3-1	32.787	8	0.000

LR test and Wald test produce similar results—for all combinations of outcome categories, we reject the null hypotheses that the outcomes are indistinguishable with respect to the explanatory variables in the model. That means, we cannot combine any two outcome categories.

As illustrated above, the validity of MNL is rested on the assumption of IIA which states that the odds for each pair of outcomes do not depend on the presence/absence of other outcomes (in other words, adding or deleting outcomes should not affect the odds among the remaining outcomes). To justify the choice of MNL, we can test whether the IIA assumption holds in our case. For this purpose, either the Hausman

[81] Cf. footnote 70.
From equatioan (6.31), it is easy to see $\beta_{1,m|n} = \cdots = \beta_{K,m|n} = 0$ is equivalent to
$(\beta_{1,\ m|Base} - \beta_{1,\ n|Base}) = \cdots = (\beta_{K,\ m|Base} - \beta_{K,\ n|Base}) = 0$

test (Hausman, 1978; Hausman & McFadden, 1984) or Small-Hsiao test (Small & Hsiao, 1985) can be used.

The Haussmann test is based on the comparison of two estimators of the same parameters. One estimator is consistent and efficient if the IIA assumption holds, while the other estimator is consistent but inefficient. For multinomial logit, maximum likelihood is consistent and efficient if the model is correctly specified. A consistent but inefficient estimator is obtained by estimating the model on a restricted set of outcomes (i.e., by eliminating one or more alternatives). If IIA holds, the dropped choices should be irrelevant, and the estimates of the parameters should be the roughly the same.

Specifically, the test (Hausman & McFadden, 1984) involves the following steps (Freese & Long, 2001):

1. Estimate the full model with all J alternatives included. This produces $\hat{\beta}_F$ and $\hat{V}_F$ (where $\hat{\beta}_F$ denotes the estimated parameters and $\hat{V}_F$ denotes their estimated covariance matrix).

2. Estimate a restricted model by eliminating one or more alternatives. This produces $\hat{\beta}_R$ and $\hat{V}_R$.

3. Let $\hat{\beta}_F^*$ be the subset of $\hat{\beta}_F$ having eliminated those corresponding coefficients not estimated in the restricted model. The following test statistic HM is asymptotically distributed as a χ^2 random variable with k degrees of freedom (where k is the number of rows in the $\hat{\beta}_R$ vector).

$$HM = \left(\hat{\beta}_R - \hat{\beta}_F^*\right)' \left[\hat{V}_R - \hat{V}_F^*\right]^{-1} \left(\hat{\beta}_R - \hat{\beta}_F^*\right) \sim \chi_k^2$$

Based on the Model 4B, we conduct the Hausman tests of IIA assumption. The null hypothesis being that:

H_0: Odds (outcome-J vs. outcome-K) are independent of other alternatives.

The results of the test (cf. Table 6-4-10) suggest that the null hypothesis of independence of irrelevant alternatives cannot be rejected[82]. In other words, we found no evidence that the odds are influenced by the numbers of categories included in the estimation.

Table 6- 4- 10: Results of Hausman Tests of IIA Assumption (Model 4B)

Omitted	chi2	Df	P>chi2	evidence
1	-1.365	9	1.000	for H_0
2	-2.713	9	1.000	for H_0
3	-0.971	9	1.000	for H_0

Note: If chi2<0, the estimated model does not meet asymptotic assumptions of the test[83].

Finally, we are aware that Hausman tests of IIA assumptions could in some case inconclusive. Specifically, the MNL is estimated with reference to a specific base category (for convenience, let's denote it as ***Base***). For a MNL with J categories of dependent variable, *J-1* tests can be computed by excluding each of the non-base categories to construct the unrestricted model, and by changing the base category, a test can also be computed for the omission of ***Base***. Note that the Hausman test could give inconsistent results if different base category is used to estimate the models. Fortunately, in our case, the dependent variable consists only of three categories. We

[82] It should be noted that in the Hausman test, one may get a rejection of the null hypothesis either if IIA is false, or if there is some other problem with the model specification, such as omitted variables that are common to two or more choices. In other words, even if IIA is correct in the abstract, it will appear as if it is violated if variables common to two choices are omitted. This is because the omitted variables are being captured in the error terms, making them appear correlated (McFadden, 2001).

[83] Hausman and McFadden (1984: p. 1226) note that the test statistics *HM* could be negative when $\hat{V}_R - \hat{V}_F^*$ is not positive semidefinite, but they suggest, according to their experience, a negative result might be taken as support for the IIA assumption. Most of the literature clearly subscribes to this view (Cheng & Long, 2007: p. 589), probably because the Hausman and McFadden suggestion is clearly convenient. Some researchers find this problematic, since a statistic which is treated as χ^2 ought not to take on negative values. Vijverberg (2011) suggests that the problem arises because of an improper conceptualization of the covariance matrix, and he proposes an alternative estimate of $\hat{V}_R - \hat{V}_F^*$ which leads to an alternative statistic that is guaranteed to be positive and that has a distribution more closely approximating the asymptotic χ^2 distribution. He strongly advocates the routine use of the alternative statistic in place of the original Hausman and McFadden statistic *HM*.
An alternative approach to the estimation of the required variance matrix would be to use the bootstrap. As noted by Cameron and Trivedi (2005), the small-sample distritution of original *HM* test statistic may well deviate substantially form the asymptotic χ^2 distribution, while the bootstrap version of the Hausman-test statistic does not require the assumption of asympototic χ^2 distribution. For technical details, see Cameron & Trivedi (2005: p. 378).
In this research, we follow the practice of most of the literature, but we are aware of the potential problem of the Huasman-test of IIA.

try all the possible base categories and in each case, the Hausman test of IIA assumption gives consistent results.

Small-Hsiao test (Small & Hsiao, 1985) could be even more inconclusive[84]. In Small and Hsiao's test[85], the sample is randomly divided into two subsamples of approximately equal size. The result of the test thus depends on how the sample is divided. Quite often, the results may differ drastically with successive executions of the same test. For this reason, we give up Small-Hsiao test and rely on Hausman test only.

C. Results and Analysis of the Multinomial Estimation (4 Alternatives)

In this section, we adopt a four-category classification for the dependent variable. Specifically, for the samples in the category of alliance, we further differentiate the equity-based and the contract-based alliance (Colombo, 2003; Colombo & Delmastro, 2001; Colombo et al., 2006; Mowery et al., 1998; Oxley, 1997; Pisano, 1989, 1990, 1991); while for the categories of in-house and outsourcing, the scopes and definitions are kept unchanged.

The equity-based R&D alliance is defined as the form of collaborative arrangement whereby the participating parties use some sort of equity-based arrangement as an umbrella structure to support their joint R&D project. Such equity-based arrangement can either be in the form of joint-venture, or it can simply manifest itself as the acquisition of minority shareholding (in particular, cross-holding of minority stakes). The contract-based R&D alliance, by contrast, is the form of collaborative

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[84] Apart from this, Small-Hsiao test and Hausman test often give contradictory information on whether the IIA assumption has been violated.

[85]. The Small-Hsiso test randomly splits the sample into two subsamples, the unrestricted MNL is then estimated on both subsamples. A weighted average of the coefficients from the two estimations is defined as:

$$\hat{\beta}_U^{S_1S_2} = \left(\frac{1}{\sqrt{2}}\right)\hat{\beta}_U^{S_1} + \left(1-\frac{1}{\sqrt{2}}\right)\hat{\beta}_U^{S_2}$$

Where $\hat{\beta}_U^{S_1}$ is a vector of coefficients estimated from the unrestricted model on the first subsample and $\hat{\beta}_U^{S_2}$ is its counterpart for the second subsample. The next step is to create a restricted sample from the second subsample by eliminating all cases with a given category of the dependent variable. The MNL is estimated using the restricted sample which yields the estimates $\hat{\beta}_R^{S_2}$ and the likelihood $L\left(\hat{\beta}_R^{S_2}\right)$. The Small-Hsiao statistic is the difference:

$$SH = -2\left[L\left(\hat{\beta}_U^{S_1S_2}\right) - L\left(\hat{\beta}_R^{S_2}\right)\right]$$

SH is asymptotically distributed as a chi2 random variable with the degrees of freedom equal to $K + 1$, where K is the number of independent variables, i.e.,

$$SH \sim \chi_{K+1}^{2}$$

arrangement in which two or more firms, by entering into a non-equity contractual relationship, combine some of their respective resources and capabilities to jointly undertake a collaborative R&D project. In short, in this section, the dependent variable—organizational mode (ORM)—is a polychotomous response *variable which has four* categories: in-house, the equity-based alliance, the contract-based alliance and outsourcing. These four categories, by the above order, are denoted as 1 to 4 respectively.

As the two types of alliance are further differentiated, the 58 alliance samples now break down into two categories—24 as the equity-based alliance and the other 34 as the contract-based alliance. Accordingly, the shares for the four categories, by their numerical order, are 43%, 16.9%, 23.9% and 16.2% respectively.

We then use these 142 observations to estimate a new four-category multinomial logit model. Table 6-4-11 reports the descriptive statistics of the variables (for correlation of the explanatory variables, please refer to Table 6-4-2 in the previous section).

Table 6- 4- 11: Descriptive Statistics for All Variables (Multinomial Analysis, 4 Alternatives)

Var. Code	Full Name	Mean (S.D.)					Min	Max
		Entire Samples (Num. of Obs.=142)	**In-house** (Num. of Obs.=61)	**The Equity-based Alliance** (Num. of Obs.=24)	**The Contract-based Alliance** (Num. of Obs.=34)	**Outsourcing** (Num. of Obs.=23)		
Dependent Variable (In-house=1; The Equity-based Alliance=2; The Contract-based Alliance=3; Outsourcing=4)								
ORM	Organization Mode						1	4
Independent Variables								
PS	Problem Structure	2.655 (0.826)	2.705 (0.803)	2.583 (0.654)	2.941 (0.919)	2.174 (0.717)	1	4
COM	Complexity	3.408 (0.764)	3.377 (0.778)	3.542 (0.833)	3.735 (0.567)	2.870 (0.626)	2	5
DEC	Decomposability	2.437 (0.803)	2.508 (0.744)	2.333 (0.868)	2.706 (0.760)	1.957 (0.767)	1	5
EKB	Existing Knowledge Base	3.592 (0.860)	4.049 (0.644)	3.625 (0.770)	3.206 (0.641)	2.913 (1.041)	1	5
COD	Codifiability	2.810 (0.825)	2.770 (0.864)	2.750 (0.737)	3.029 (0.834)	2.652 (0.775)	1	5
TEA	Teachability	2.592 (0.773)	2.574 (0.741)	2.500 (0.590)	2.824 (0.797)	2.391 (0.941)	1	5
SDK	Social Distribution of Knowledge	3.239 (1.038)	3.377 (0.916)	3.125 (1.076)	2.735 (0.931)	3.739 (1.176)	1	5
DU	Demand Uncertainty	2.408 (0.852)	2.410 (0.761)	2.333 (0.816)	2.500 (0.992)	2.348 (0.935)	1	5
HAS	Human Asset Specificity	1.415 (0.633)	1.443 (0.620)	1.417 (0.776)	1.441 (0.613)	1.304 (0.559)	1	4
PAS	Physical Asset Specificity	1.937 (0.755)	2.049 (0.784)	1.958 (0.859)	1.971 (0.717)	1.565 (0.507)	1	4
AP1	Appropriability1	3.085 (0.926)	3.115 (0.877)	3.292 (0.806)	2.794 (1.067)	3.217 (0.902)	1	5
AP2	Appropriability2	3.148 (0.663)	3.262 (0.705)	3.458 (0.588)	2.853 (0.558)	2.957 (0.562)	2	5

Table 6- 4- 12: Model 5A: Multinomial Logit Estimation Results (Four Alternatives)

Multinomial logistic regression
Number of cases 'correctly predicted' = 91 (64.1%)

Log likelihood = -122.55

Number of obs = 142
LR chi2(36) = 124.26
Prob > chi2 = 0.0000
Pseudo R^2 = 0.336

	2 (The Equity-based Alliance)						3 (The Contract-based Alliance)						4 (Outsourcing)					
	Predicted Sign for Coef.	*Coef. (Std. Err.)*	*Z*	*p-value*		*RRR (Std. Err.)*	*Predicted Sign for Coef.*	*Coef. (Std. Err.)*	*z*	*p-value*		*RRR (Std. Err.)*	*Predicted Sign for Coef.*	*Coef. (Std. Err.)*	*z*	*p-value*		*RRR (Std. Err.)*
const		2.692 (4.002)	0.67	0.501				14.408 (4.281)	3.37	0.001	***			19.524 (5.048)	3.87	0.000	***	
PS	-(?)	0.094 (0.514)	0.18	0.854		1.099 (0.564)	-(?)	0.106 (0.494)	0.22	0.830		1.112 (0.549)	-	-0.927 (0.651)	-1.42	0.154		0.396 (0.258)
COM	+(?)	1.385 (0.575)	2.41	0.016	**	3.995 (2.297)	+(?)	0.769 (0.541)	1.42	0.155		2.157 (1.168)	-	-0.946 (0.782)	-1.21	0.227		0.388 (0.304)
DEC	-	-1.547 (0.661)	-2.34	0.019	**	0.213 (0.141)	-	-1.090 (0.627)	-1.74	0.082	*	0.336 (0.211)	-	-0.738 (0.873)	-0.85	0.398		0.478 (0.418)
EKB	-	-1.908 (0.526)	-3.63	0	***	0.148 (0.078)	-	-2.259 (0.511)	-4.42	0.000	***	0.104 (0.053)	-	-2.965 (0.611)	-4.85	0.000	***	0.052 (0.031)
COD	-	-0.365 (0.434)	-0.84	0.401		0.694 (0.302)	-	0.004 (0.437)	0.01	0.993		1.004 (0.439)	-	0.205 (0.568)	0.36	0.718		1.227 (0.696)
TEA	-	-0.110 (0.453)	-0.24	0.809		0.896 (0.406)	-	0.206 (0.387)	0.53	0.595		1.228 (0.475)	-	-0.082 (0.567)	-0.14	0.885		0.921 (0.523)
SDK	-	-0.093 (0.289)	-0.32	0.747		0.911 (0.264)	-	-0.750 (0.293)	-2.56	0.010	***	0.472 (0.138)	-	0.218 (0.412)	0.53	0.596		1.244 (0.512)

DU	-	-0.111 (0.375)	-0.30	0.766		0.895 (0.335)	-	-0.168 (0.336)	-0.50	0.617		0.845 (0.284)	-	0.430 (0.500)	0.86	0.390		1.537 (0.769)
HAS	-	-0.539 (0.473)	-1.14	0.255		0.584 (0.276)	-	-0.426 (0.495)	-0.86	0.389		0.653 (0.323)	-	-0.094 (0.768)	-0.12	0.903		0.911 (0.699)
PAS	**-**	0.266 (0.446)	0.60	0.551		1.304 (0.582)	-	-0.440 (0.426)	-1.03	0.302		0.644 (0.274)	-	-1.505 (0.671)	-2.24	0.025	**	0.222 (0.149)
AP1	-	0.535 (0.381)	1.40	0.16		1.708 (0.651)	-	0.026 (0.342)	0.08	0.940		1.026 (0.351)	-	0.292 (0.513)	0.57	0.570		1.338 (0.687)
AP2	-	0.829 (0.480)	1.73	0.084	*	2.290 (1.099)	-	-1.137 (0.457)	-2.49	0.013	**	0.321 (0.147)	-	-1.053 (0.631)	-1.67	0.095	*	0.349 (0.220)

In-house (ORM==1) is the base outcome

*** p<0.01; ** p<0.05; * p<0.1

Table 6- 4- 13: Classification Table (Model 5A)

		Predicted				*Percentage Correct*
		1	2	3	4	
Actual	1	49	4	4	4	80.3%
	2	9	4	4	7	16.7%
	3	9	0	19	6	55.9%
	4	2	1	1	19	82.6%
Overall Percentage						64.1%

As a first step, we estimate a model (5A) that includes all the 12 explanatory variables (in-house being the reference category). The results are presented in Table 6-4-12.

Overall, the estimation results of Model 5A are structurally similar to that of Model 4A, but with some new interesting information. In the text that follows, we will discuss the results in detail.

Table 6- 4- 14: A Comparison of the Estimation Results of Model 5A and Model 4A

Alternative	**Model 4A** ***Significant variables***	**Model 5A** ***Significant variables***	**Alternative**
Alliance	EKB***(=-1.986) COM**(=1.021) DEC**(=-1.255) SDK*(=-0.407) AP2(=-0.197)	EKB***(=-1.908) COM**(=1.385) DEC**(=-1.547) SDK=(-0.093) AP2*(=0.829)	**The Equity-based Alliance**
		EKB***(=-2.259) COM(=0.769) DEC*(=-1.090) SDK***(=-0.750) AP2**(=-1.137)	**The Contract-based Alliance**
Outsourcing	EKB***(=-2.915) PAS**(=-1.384) AP2(=0.887)	EKB***(=-2.965) PAS**(=-1.505) AP2*(=-1.053)	**Outsourcing**

*** p<0.01; ** p<0.05; * p<0.1

The Equity-based alliance

For the alternative of the equity-based alliance, 8 of the 12 coefficients for the explanatory variables bear the "right" sign as predicted by the theory, 4 of them are significant at the level of 10% or higher, of which 3 are KBV variables (EKB, COM, DEC) and 1 is TCE variable (AP2).

With the two types of alliance further differentiated, we are particular interested to see whether the results (for both types of alliance) in the new model are any different from the results for the alternative of alliance in the old model (see Table 6-4-14).

For the moment, the comparison to be made is between the results for the equity-based alliance in model 5A with that for the alternative of alliance in model 4A.

We note that in both settings, the coefficients for EKB, DEC and COM come up with the same sign at the same level of significance, but the magnitude of their effects are readily distinguishable. In particular, the effect of COM for the category of the equity-based alliance tends to be stronger than for the category of alliance in model 4A.

In the new model, the coefficient of EKB is, as before, negative and significant at the level of 1%, suggesting that a higher EKB decreases the relative probability of choosing the equity-based alliance over internal organization. More accurately, the RRR for EKB is 0.148 (by contract, in model 4A, the figure is 0.137), indicating that a one-unit increase in EKB decreases the probability of choosing the equity-based alliance over in-house by 85.2%.

The coefficient for COM and DEC are both significant at the level of 5%. The positive sign for COM implies that an increase in COM increases the relative probability of choosing the equity-based alliance over in-house, while a negative sign for DEC, on the contrary, indicates that a higher DEC value makes the equity-based alliance less likely to be chosen over in-house. In short, the signs of the two coefficients suggest that, compared with in-house, the equity-based alliance is more preferred for solving more complex problem, but is less preferred for solving non-decomposable problem.

Up to now, the results of the new model carry seemingly little new information. However, we note that there are some non-trivial differences between the two models. Firstly, as have been pointed out above, the magnitude of the COM's effect in the current setting is greater than that for the alternative of alliance in model 4A. Specifically, the RRR for COM in the current setting is 3.995, meaning that a one unit increase in COM makes it almost 4 times more likely to choose the equity-based alliance over in-house; while in model 4A, the corresponding figure is only 2.776.

Apart from this, there is one perhaps more substantial difference between the two models. That is, the effects of AP2 are quite different in the two models. In model 4A, AP2 is not at all significant for the alternative of alliance (p=0.567); while in the new model, AP2 shows up with a significant coefficient for both types of alliance, and more interestingly, with opposite signs[86]. For the category of the equity-based alliance, its coefficient is positive and significant at the level of 10% (p=0.084), suggesting that a higher AP2 value adds to the relative probability of choosing the equity-based alliance over in-house. The RRR (2.29) further confirms the magnitude of the effect is such that a one-unit increase in AP2 makes it 2.29 times more likely to choose the equity-based alliance over in-house. In terms of *relative* probability (against the baseline category of in-house), this result is inconsistent with theoretical prediction, since in the transaction costs theory, internal organization is generally believed to be the most efficient mode for preventing the leakage of appropriable knowledge. However, if we focus more narrowly on the opposite signs of AP2's coefficient under the two types of alliance, the result could at least be partially justified[87]. For the time being, we would not go into details, but further discussion on this point will be developed in the text below.

Finally, we also note that while the coefficient of SDK is significant for the alternative of alliance in model 4A, in the new model, it is significant only for the contract-based alliance but not for the equity-based alliance.

The Contract-based Alliance

The contract-based alliance is a second type of alliance. For this alternative, 8 of the 12 coefficients for the explanatory variables bear a theoretically consistent sign, 4 of them are significant at the level of 10% or higher, of which 3 are KBV variables (EKB, SDK and DEC) and 1 are TCE variable (AP2).

The coefficient of EKB is negative and again the most significant among all variables (at the level of 1%). The value of its RRR (0.104) indicate that a one-unit increase in EKB decreases the relative probability of choosing the contract-based alliance over in-house by 89.6%, which, by contrast, is roughly of the same magnitude as that for the equity-based alliance (RRR=0.148).

The negative coefficient of SDK is also significant at the level of 1%. This result carries some interesting message. As have been noted, in model 4A, the coefficient of SDK is significant for the alternative of alliance (but merely at the marginal level

[86] Although less significant, the estimated coefficients of PAS share similar pattern to that for AP2, Specifically, for the alternative equity-based alliance, its coefficient is positive (which is at odds with the theory), and for the alternatives of contract-based allince and outsourcing, the coefficient are negative.

[87] As we will see later, AP2's impacts on the absolute probabilities of choosing the two types of alliance are in two directions as well.

of 10%); while in the new model, it is highly significant for the contract-based alliance but not at all significant for the equity-based alliance (p=0.747). Putting together all these information, the following implication seems to emerge—when a R&D project involves highly socially distributed knowledge, alliance in general and the contract-based alliance in particular is less efficient than in-house, accordingly, alliance (especially the contract-based alliance) is less likely to be chosen over in-house. More accurately, *ceteris paribus*, a one point increase in SDK significantly reduces the relative probability of choosing the contract-based alliance over in-house by 52.8% (RRR=0.472); at the same time, it reduce the relative probability of choosing the equity-based alliance over in-house only by 9% (RRR=0.911), and this effect is not at all significant. These messages also imply, as far as the effects of SDK are concerned, it might not be appropriate to put the two types of alliance in the same category, since such mixture neutralizes SDK's very different impact on these two alternatives and it tends to understate its true importance in the organizational choice.

From a theoretical point of view, given the fact that, unlike equity-based alliances, contract-based alliances do not generally have access to such governance mechanisms as high bandwidth communication channels, collocation of team members, and centralized administrative coordination (Heiman & Nickerson, 2002, 2004; Zander & Kogut, 1995), it is reasonable to argue that the contract-based alliance is particularly not good at mobilizing socially distributed knowledge. Therefore, the result that an increase in SDK has a stronger and more significant impact on the contract-based alliance than the equity-based alliance could be well-justified.

Recall that for the alternative of the equity-based alliance, the coefficients for COM (positive) and DEC (negative) are both significant at the level of 5%; while for the current alternative of the contract-based alliance, the positive coefficient of COM is no longer significant and the negative coefficient for DEC is significant only at the level of 10%.

More accurately, the RRR of COM for the current alternative is 2.157, which, if converted into the change in relative probability in response to a one-unit increase in COM, is apparently smaller than that for the equity-based alliance (RRR=3.995). This implies, the effect of COM for the current alternative is both weaker and less significant than that for the the equity-based alliance. To put this more explicitly, it means, as the complexity of the problem to be solved tends to be higher, alliance in general is more likely to be chosen over in-house, but the increased probability goes more to the equity-based alliance than to the contract-based alliance, probably because the equity-based alliance is supported by a whole set of more powerful governance apparatus that are not or less available to the contract-based alliance. These governance apparatus include, among others, enhanced incentive alignment associated with shared equity (Mowery et al., 1996b; Oxley, 1997; Gary P. Pisano, 1989), and again, high bandwidth communication channel, collocation of team members, centralized administrative coordination, unified communication codes etc. (Heiman & Nickerson, 2002, 2004; Zander & Kogut, 1995).

The RRR of DEC for the current alternative is 0.336, which, by a mechanical comparison, suggests that the effect of DEC for the current alternative is roughly of the same magnitude as that for the equity-based alliance but is less significant (RRR=0.213).

For the contract-based alliance, AP2 is the fourth variable with a significant coefficient. Specifically, its coefficient is negative and significant at the level of 5% (p=0.012), suggesting that a higher AP2 value reduces the relative probability of choosing the contract-based alliance over in-house. As have been emphasized above, the signs of AP2's coefficients under the two types of alliance are different. This again reminds us that the two types of alliance probably cannot be collapsed into the same category, since AP2's[88] impacts on these two categories are even in opposite directions.

From a theoretical point of view, the different signs for the two types of alliance could at least be partially justified on two grounds. In the first place, equity-based alliances are supported by shared ownership, which improve the incentive alignment in the face of opportunism by moderating the opportunistic inclinations of the participating parties (Mowery et al., 1996b; Oxley, 1997; Gary P. Pisano, 1989). Moreover, the administrative facilities that come with shared ownership and hierarchical structure furnish the equity-based alliance with enhanced administrative controls over unintended leakage of appropriable knowledge(Oxley & Sampson, 2004; Oxley & Wada, 2009). Overall, the results suggest, the two types of alliance differ systematically in terms of their ability to reduce/prevent leakage of appropriable knowledge. The equity-based alliance, equipped with better incentive alignment, superior administrative apparatus, is far more effective than the contract-based alliance in dealing with the problem of appropriability. As we will see later, this conclusion could be further reinforced by observing that AP2's impacts on the

[88] It is interesting to note that the sign of PAS's coefficient (which is also TCE variable) for the two alternatives are different as well.

absolute probabilities of choosing these two alternatives are also in two different directions.

Outsourcing

For the alternative of outsourcing, 8 of the 12 variables carry a theoretically consistent sign, and we note that they are exactly the same set of variables as that in model 4A. However, in the new model of 5A, one more variable (AP2) has a significant coefficient at the level of 10% or higher, making the overall number three (EKB, PAS, AP2), of which 1 is KBV variable and 2 are TCE variables.

The coefficient for EKB is negative and is significant at the level of 1%. The RRR for EKB (0.052) indicates that a one unit increase in EKB decrease the relative likelihood of choosing outsourcing over in-house by 94.8%, which, if compared with the corresponding figure in model 4A (RRR=0.054), is *almost* identical.

Compared with other alternatives, transaction costs considerations are seemingly playing a more decisive role for the choice of outsourcing.

PAS, which has traditionally been viewed by TCE as one of the most important determinants of the firm boundary, is significant only for the category of outsourcing in model 5A. This result is essentially the same as that of model 4A. To be more specific, in model 5A, the coefficient of PAS is also negative, meaning that a higher degree of physical asset specificity makes outsourcing less likely to be chosen over in-house. The RRR of PAS (0.222) further confirms that, in response to a one-unit increase in PAS, the new model predicts roughly the same magnitude of change as that by model 4A (0.272).

AP2 is the second TCE variable that is significant in model 5A. We note that AP2 performs differently in the new and old model. Specifically, in model 4A, the coefficients of AP2 are not significant for any of the alternative, but in the new model, they become persistently significant. For the current alternative, its coefficient is negative and significant at the level of 10% (p=0.095), the RRR (0.349) further indicates that a one unit increase in AP2 makes it 65.1% less likely to be chosen over in-house.

Summing up, model 5A performs reasonably well. Of the 142 observations, it correctly predicts the organizational mode for 91 cases (see Table 6-4-13), which yields a “hit rate” of 64 %, a level much higher than random prediction (25%), or if all observations were assigned to the most frequently observed alternative (42.96%).

However, we note again that there are large disparities in hit rates among different alternatives—for the alternatives of in-house and outsourcing, the prediction is fairly accurate (the hit rate being 80.3% and 82.6% respectively); for the alternative of the contract-based alliance, the "hit rate" is within the acceptable range (55.9%); while for the alternative of the equity-based alliance the "hit rate" is quite poor (16.7%). Given the underperformed "hit rate" for this alternative, it is somewhat paradoxical to note that among the 12 coefficients for this alternative, 4 are estimated to be significant. We are not particularly sure about the real cause for such disparities. It could either because we miss some variables which are highly relevant for the choice of the equity-based alliance, or it could result from measurement errors. To the author, it seems that the later cause is more likely to be the source of the problem. Specifically, in our research, data are collected by survey, and the respondents are requested to provide information regarding the organizational modes and certain characteristics of their R&D projects. In our survey, an equity-based alliance is defined as a joint R&D project supported by some sort of equity-based arrangements between the partner firms, be it a joint venture, or simply minority shareholding (in particular, cross-holding of minority stakes). In the text of our questionnaire, we emphasize in particular that, for our purpose, ***not** all R&D projects undertaken in a joint venture are readily classified as organized by the equity-based alliance*; only those projects that rely critically on such equity-based arrangements as the umbrella structure for their development and implementation can be legitimately classified under this category. We further clarify in the text of our questionnaire that, "to rely critically on an equity arrangement as the umbrella structure" means, without such equity arrangement, the R&D project would not have been undertaken by the participating parties.

In the data colleting stage, we notice that less careful respondents often ignore the restriction on the above definition. As a result, they tend to report ***all*** R&D projects undertaken in the joint-venture indiscriminately as organized by the equity-based alliance. We take measures to address the problem and to improve the data quality, but for of the respondents, such an inclination can still be observed. In short, we note that for all the four alternatives, the equity-based alliance is most liable to the problem of measurement error, and we think this could probably explain why the "hit rate" is particularly low for this alternative.

Having discussed the results for model 5A, we then try if we can simplify the model specification by eliminating variables that are highly insignificant.

In simplifying the model, we use the same criteria as that in the previous section (see p. 257). By these criteria, four variables (COD, TEA, DU & AP1) are picked up. We then test for the joint omission of these four variables, the null hypothesis being that the parameters are zero for all the variables of COD, TEA, DU and AP1. The likelihood ratio test comes up with a Chi2 (12) = 5.596 with *p*-value=0.918, suggesting that the null hypothesis could not be rejected. In other words, the parameters for the above four variables could all be safely assumed to be zero and be dropped from regression. We then estimate the new model, and the results are presented in Table A-6-3 in the appendix II.

In terms of basic structure, the new model is highly similar[89] to that of model 5A. In certain respect (e.g. adjusted R^2, percentage of coefficients with a theoretically-consistent sign), the new model is better than the old one. However, we find that with the elimination of the four variables, the already poor hit rates for the two types of alliance are getting even worse (see Table A-6-4 in the appendix II). Specifically, in the new model, the overall "hit rate" drops down slightly from 64.1% to 62%. This might not be a problem if this effect distributes more evenly among the four alternatives. However, this is not the case. For the the equity-based alliance, the hit rate falls from 16.7% to an even worse 12.5%, and for the contract-based alliance, the figure drops down from 55.9% to less than 50% (47.1%). Given these unfavourable results, it would be prudent not to drop these variables. Below, our discussions on the marginal effects are based on model 5A. We would, however, confine our discussions primarily to the six variables whose coefficients are significant.

As a final remark, it should be reminded that all the above analysis on the estimation results are based on ***relative*** probabilities (over baseline alternative), while the probability of choosing the baseline alternative is itself a variable. Therefore, we still don't know exactly how the absolute probability of each of the four alternatives is affected by the change of each variable. Below, we would explore this problem.

Marginal Effects

Based on model 5A, we calculated the marginal effects (at sample means) of all the twelve explanatory variables on each of the four alternatives. Table 6-4-15 exhibits the results.

[89] Again, in the corresponding alternatives of these two models, the same set of variables are estimated to be significant at the same level of significance

Table 6- 4- 15: Marginal effects at Sample Means (Model 5A)

	1 (In-house)				2 (The Equity-based Alliance)				3 (The Contract-based Alliance)				4 (outsource)			
	Pr(ORM=1|x= $\overline{x}$)=0.483				*Pr*(ORM=2|x= $\overline{x}$)=0.211				*Pr*(ORM=3|x= $\overline{x}$)=0.238				*Pr*(ORM=4|x= $\overline{x}$)=0.068			
	dy/dx (Std. Err)	*z*	*p-value*		*dy/dx (Std. Err)*	*z*	*p-value*		*dy/dx (Std. Err)*	*z*	*p-value*		*dy/dx (Std. Err)*	*z*	*p-value*	
PS	0.008 (0.104)	0.08	0.935		0.024 (0.076)	0.31	0.756		0.030 (0.078)	0.38	0.706		-0.062 (0.041)	-1.51	0.131	
COM	-0.199 (0.114)	-1.75	0.081	*	0.206 (0.083)	2.49	0.013	**	0.085 (0.085)	1.00	0.316		-0.092 (0.050)	-1.82	0.069	*
DEC	0.307 (0.130)	2.37	0.018	**	-0.192 (0.100)	-1.93	0.054	*	-0.108 (0.102)	-1.06	0.289		-0.007 (0.051)	-0.13	0.893	
EKB	0.551 (0.111)	4.98	0	***	-0.162 (0.076)	-2.14	0.032	**	-0.266 (0.080)	-3.34	0.001	***	-0.123 (0.052)	-2.38	0.017	**
COD	0.030 (0.087)	0.35	0.729		-0.064 (0.068)	-0.95	0.345		0.016 (0.072)	0.22	0.826		0.018 (0.033)	0.56	0.578	
TEA	-0.010 (0.085)	-0.12	0.908		-0.027 (0.069)	-0.40	0.692		0.044 (0.063)	0.70	0.484		-0.007 (0.032)	-0.21	0.831	
SDK	0.089 (0.058)	1.54	0.123		0.019 (0.045)	0.43	0.668		-0.135 (0.045)	-3.02	0.003	***	0.027 (0.025)	1.10	0.272	
DU	0.017 (0.073)	0.23	0.818		0.016 (0.056)	-0.29	0.773		-0.032 (0.054)	-0.59	0.552		0.031 (0.029)	1.07	0.284	
HAS	0.107 (0.098)	1.09	0.276		0.067 (0.073)	-0.91	0.360		-0.049 (0.081)	-0.60	0.549		0.009 (0.045)	0.19	0.848	
PAS	0.073 (0.087)	0.84	0.404		0.088 (0.069)	1.28	0.200		-0.069 (0.071)	-0.98	0.329		-0.092 (0.043)	-2.14	0.033	**
AP1	-0.067 (0.072)	-0.94	0.350		0.084 (0.058)	1.44	0.151		-0.027 (0.056)	-0.48	0.631		0.010 (0.030)	0.35	0.730	
AP2	0.081 (0.087)	0.93	0.353		0.210 (0.070)	3.01	0.003	***	-0.231 (0.076)	-3.05	0.002	***	-0.060 (0.041)	-1.45	0.147	

*** p<0.01; ** p<0.05; * p<0.1

As shown in table 6-4-14, for the baseline alternative of in-house, the marginal effects of three variables (EKB, COM and DEC) are significant at sample means, of which the marginal effect of EKB is the strongest both in terms of its magnitude and the level of significance. At this point, a one-unit increase in EKB adds to the probability of choosing in-house by 55.1 % (significant at the level of 1%), at the same time, it reduces the probability of choosing all the other three alternatives by 16.2% (p=0.032), 26.6% (p=0.001) and 12.3% (p=0.017) respectively.

By contrast, the marginal effect of COM for the baseline alternative is of a smaller magnitude and at a lower level of significance. At sample means, a one-point increase in COM reduces the probability of choosing in-house by 19.9% (p=0.081), and it adds to the probabilities of choosing both types of alliance (in particular, the the equity-based alliance). To be more exact, at this point, a one-point increase in COM increases the chances of choosing the equity-based alliance by 20.6% (p=0.013), by contrast, the corresponding figure for the contract-based alliance is only 8.5% (p=0.316). As for outsourcing, the same change of COM makes it 9.2% (p=0. 069) less likely to be chosen.

For the baseline alternative, DEC is the third variable whose marginal effect is significant at sample mean. At this point, a higher DEC favours the choice of in-house and discourages the choice of both types of alliance. To be more accurate, a one-point increase in DEC adds to the probability of choosing in-house by 30.7% (p=0.018), and this comes mainly via the reduction in the probabilities of choosing both types of alliance—for the equity-based alliance, the predicted probability is reduced by 19.2% (p=0.054); and for the contract-based alliance, by 10.8%; while the probability of choosing outsourcing is virtually unaffected (less than 1%).

At sample means, the marginal effects of SDK, PAS and AP2 are all positive for the alternative of in-house, meaning that a higher value of any of these variables adds to the chance of choosing in-house, but all these effects are not significant. However, the marginal effects for these three variables are significant for at least one of the alternatives.

For SDK, a one-point increase at the mean point makes it 8.9% more likely to choose in-house (p=0.123); at the same time, it reduces the probability of choosing the contract-based alliance by 13.5% and this effect is significant at the level of 1%. As for the alternatives of equity-base alliance and outsourcing, we note that SDK's marginal effects are much smaller and less significant. Finally, it might be worth noting that SDK's marginal effects on the two types of alliance are in opposite directions. This suggests, in terms of their respective abilities in mobilizing socially distributed knowledge, the two types of alliance are quite different.

The patterns for PAS's and AP2's marginal effects are rather similar. Specifically, for in-house and the equity-based alliance, the marginal effects are positive, while for the contract-based alliance and outsourcing, the marginal effects are negative[90]. The results tend to suggest, compared with the contract-based alliance and outsourcing, in-house and the equity-based alliance are more effective in overcoming transactional problems, be it the problem of asset specificity, or the problem of

[90] However, that the marginal effect of PAS is significant for only one of the alternatives (outsourcing), whereas for AP2, the marginal effects are significant for both types of alliance.

appropriability. Such difference could in turns be attributed to the fact that hierarchy and equity-based arrangements are equipped with superior incentive alignment and more powerful administrative apparatus that help to curb or mitigate the opportunistic inclinations of the participating parties (Mowery et al., 1996b; Oxley, 1997; Oxley & Sampson, 2004; Oxley & Wada, 2009; Gary P. Pisano, 1989; Williamson, 1991), or more interestingly, to cultivate the greater asset co-specialization[91] (Dyer, 1996; Sheth & Parvatiyar, 1992).

In the above analysis, all the marginal effects are calculated at one single point—the sample means. As have been illustrated, a better way to demonstrate the marginal effect is to show how the predicted probability of each alternative is affected by the point-by-point increase of each explanatory variable.

Based on model 5A, we calculate the marginal effects of each variable on a point-by-point incremental basis. The results are presented in table 6-4-16 and graphically as Figure 6-4-6 to Figure 6-4-11.

In the discussions that follow, we would confine our attention mainly to the two types of alliance. For the alternatives of in-house and outsourcing, we find that the further differentiation of the two types of alliance adds little new information.

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[91] According to Teece (1986, 2007), co-specialized assets are a particular class of complementary assets whereby the value of an asset is a function of its use in conjunction with other particular assets. With co-specialization, joint use is value enhancing. In the context of inter-firm collaboration, co-specialization represents a specific, irreversible investment by a partner-firm in its relation with another partner-firm.
In this view, asset specificity is viewed more as an outcome, rather than the cause of the choice of internal organization and equity-based alliance. Relatedly, these two modes are more efficient in the face of asset specificity not so much because they economize on transaction costs associated with asset specificity, but more because asset co-specialization tends to reduce products costs.

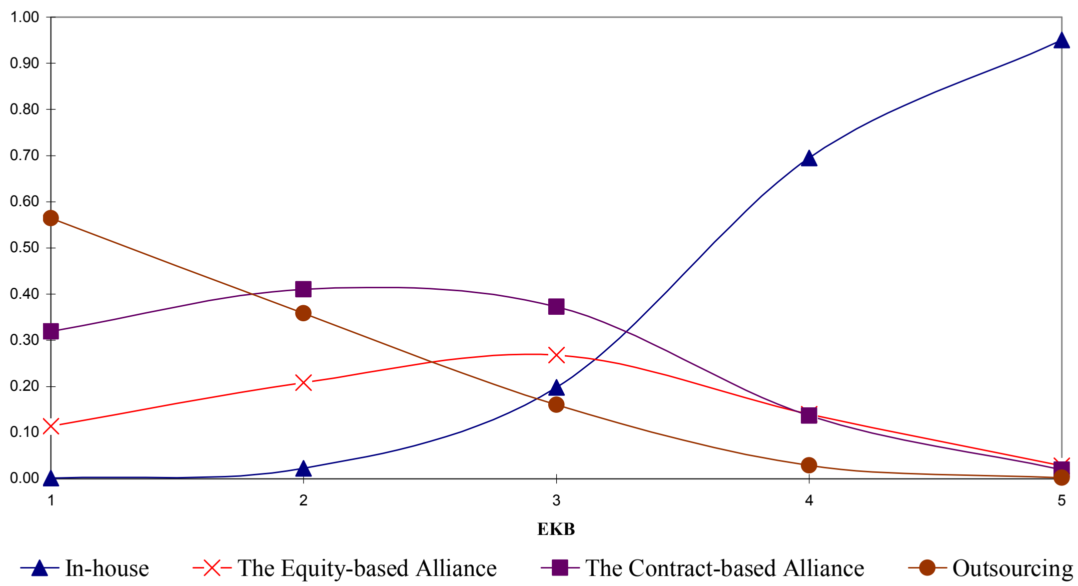
Table 6- 4- 16: The Effects of the Point-by-Point Increase of Each Explanatory Variable on the Predicted Probability of Each Alternative (Model 5A) ‡

		1	2	3	4	5
COM	In-house	0.406	0.568	0.551	0.351	0.150
	The Equity-based Alliance	0.006	0.035	0.137	0.348	0.594
	The Contract-based Alliance	0.032	0.095	0.199	0.273	0.252
	Outsourcing	0.556	0.302	0.114	0.028	0.005
DEC	In-house	0.128	0.351	0.648	0.852	0.944
	The Equity-based Alliance	0.517	0.302	0.119	0.033	0.008
	The Contract-based Alliance	0.303	0.279	0.173	0.077	0.029
	Outsourcing	0.052	0.068	0.060	0.038	0.020
EKB	In-house	0.002	0.023	0.198	0.695	0.950
	The Equity-based Alliance	0.114	0.208	0.268	0.140	0.028
	The Contract-based Alliance	0.320	0.411	0.373	0.136	0.019
	Outsourcing	0.565	0.358	0.161	0.029	0.002
SDK	In-house	0.234	0.351	0.460	0.540	0.585
	The Equity-based Alliance	0.126	0.172	0.206	0.220	0.217
	The Contract-based Alliance	0.620	0.439	0.272	0.151	0.077
	Outsourcing	0.020	0.038	0.061	0.089	0.120
PAS	In-house	0.376	0.487	0.521	0.509	0.472
	The Equity-based Alliance	0.128	0.217	0.303	0.386	0.467
	The Contract-based Alliance	0.280	0.234	0.161	0.101	0.061
	Outsourcing	0.216	0.062	0.015	0.003	0.001
AP2	In-house	0.124	0.289	0.468	0.469	0.321
	The Equity-based Alliance	0.009	0.049	0.181	0.416	0.653
	The Contract-based Alliance	0.701	0.526	0.274	0.088	0.019
	Outsourcing	0.166	0.136	0.077	0.027	0.006

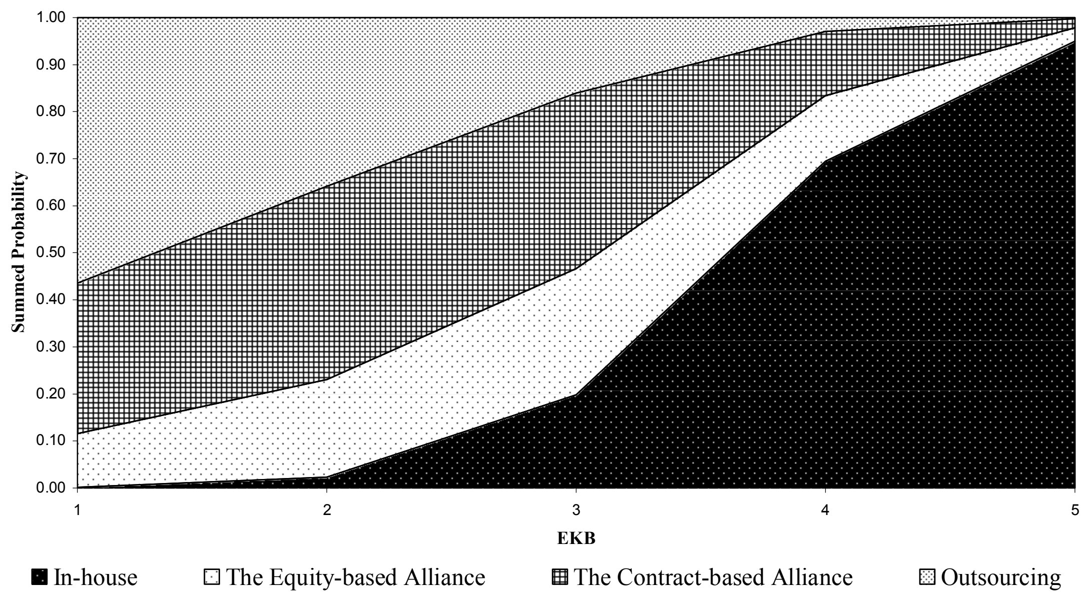
‡ When calculating the effect of a variable, other variables are held constant at their sample means.

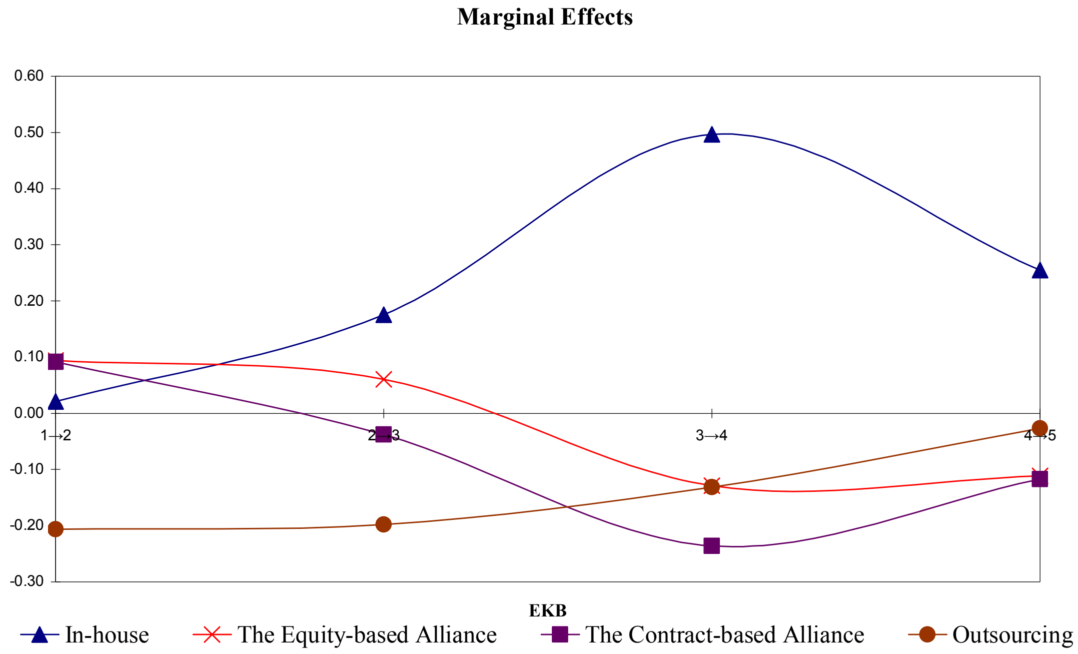
Figure 6- 4- 6: The Effects of the Point-by-Point Increase of EKB on the Predicted Probability of Each Alternative (Model 5A)

Predicted Probability Line Plot



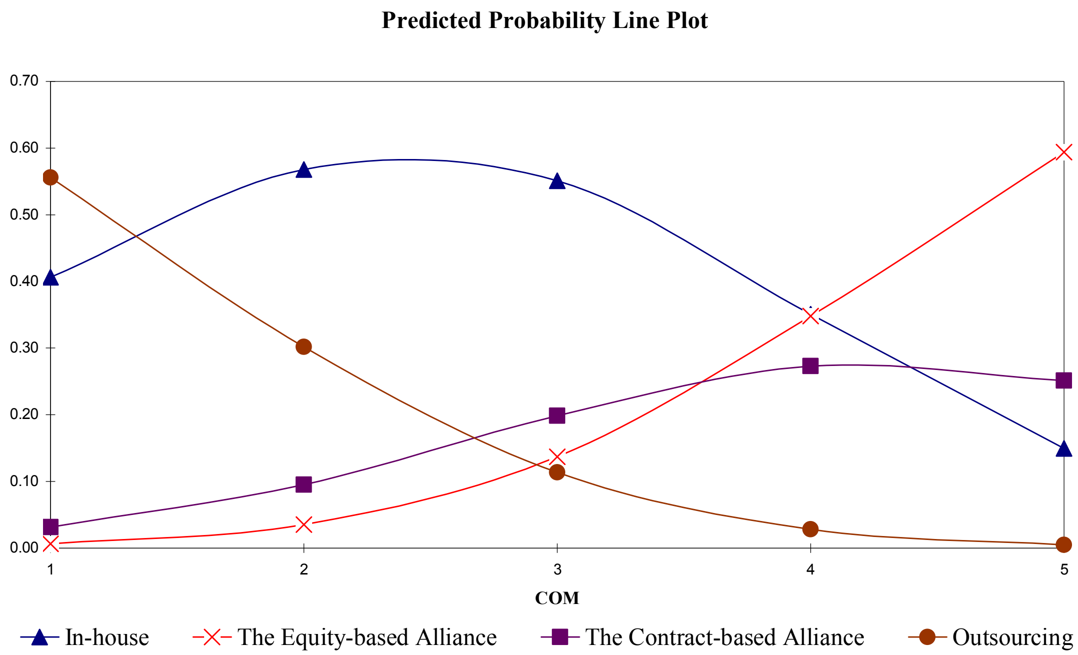
Summed Predicted Probability Area Plot

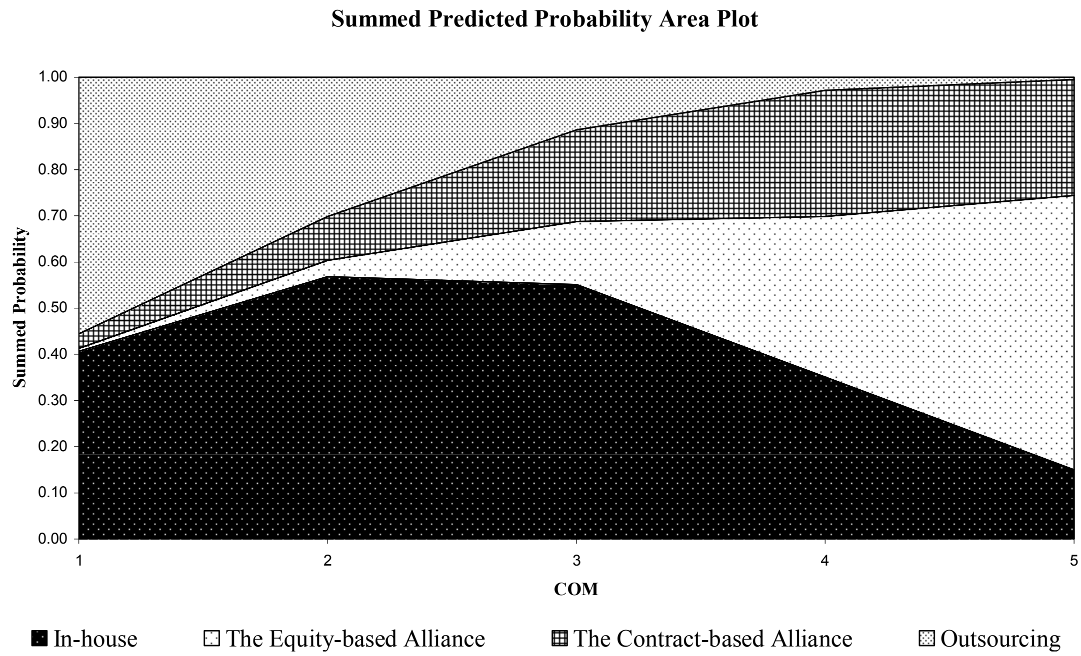


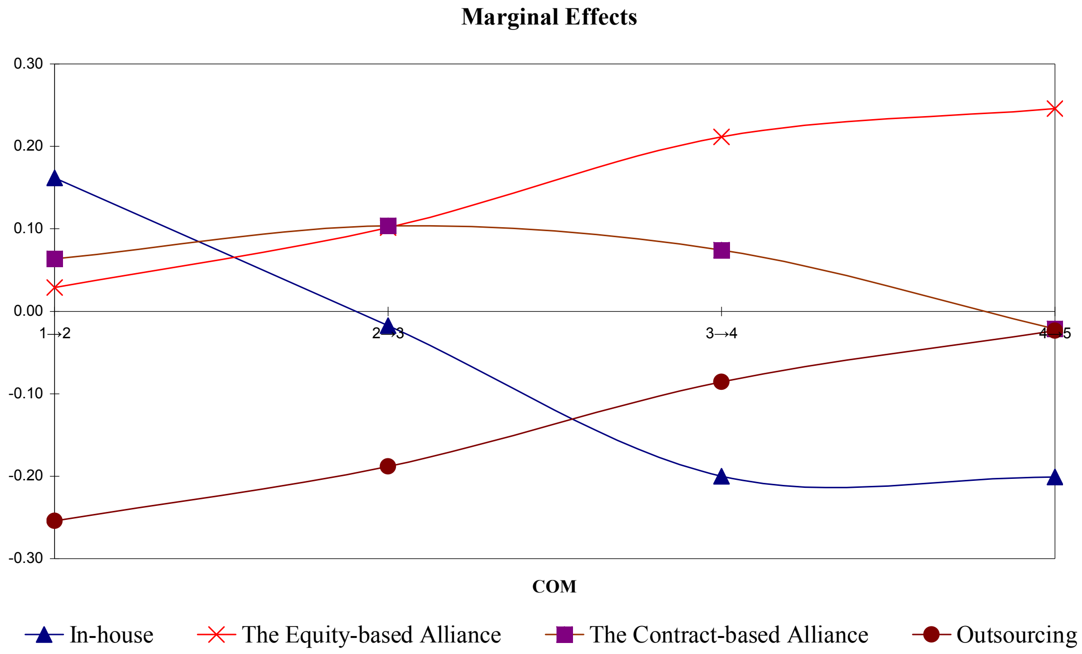


As shown in Figure 6-4-6, EKB's effects on the two types of alliance are structurally similar. At lower value of EKB, the increase of EKB adds to the predicted probabilities of choosing both alternatives (positive marginal effect), while at higher value of EKB, it works to the contrary (negative marginal effect). Summing up, the message is, holding all other variables constant at their sample means, at lowest value of EKB, outsourcing is most likely to be chosen; in the medium range of EKB, alliance in general and *the contract-based alliance in particular* is the most preferred option; while for higher value of EKB, in-house is the first choice. To put these more explicitly, these results imply: when a firm is confronted with a problem for which it has little background knowledge, it is more likely that the firm would choose outsourcing as the organizational mode. If, on the contrary, a firm commands a high level of background knowledge relevant to the problem, it tends to organize the problem-solving internally. Between these two polar situations alliances are most likely to be chosen, with the contract-based alliance being particularly preferred.

Figure 6- 4- 7: The Effects of the Point-by-Point Increase of COM on the Predicted Probability of Each Alternative (Model 5A)

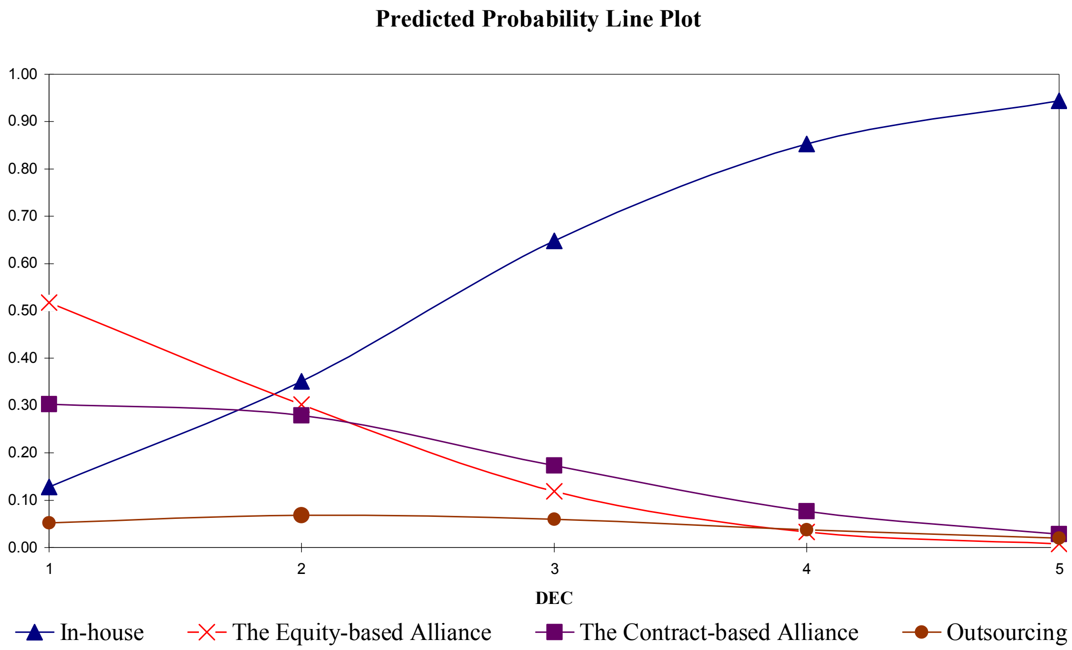


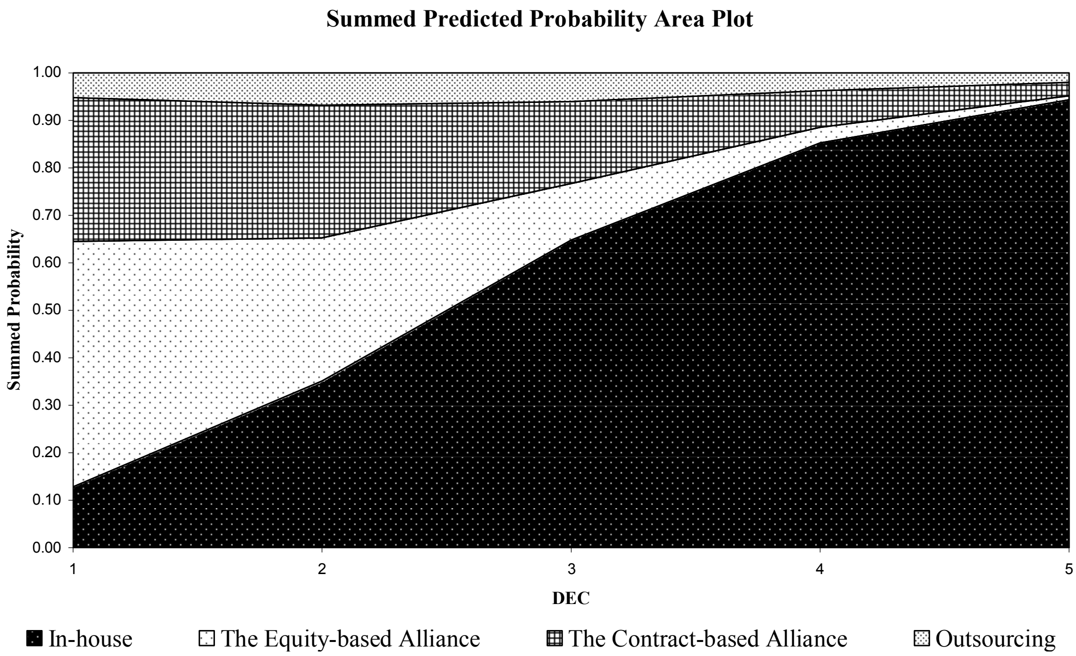




In Figure 6-4-7, we note that of the two types of alliance, the equity-based alliance is more sensitive to the increase of COM. Specifically, as COM varies from 1 to 5, the probabilities of choosing both types of alliance tend to increase, but on average, COM's marginal effect for the equity-based alliance is almost 3 times greater than for the contract-based alliance (14.7% vs. 5.5% per one-point increase). Summing up, the message is, *ceteris paribus*, outsourcing is most likely to be chosen for solving problems of lowest complexity; and internal organization is the first option for solving problems of ordinary complexity; while the two types of alliance, and in particular, the equity-based alliance, is most likely to be chosen for solving highly complex problems.

Figure 6- 4- 8: The Effects of the Point-by-Point Increase of DEC on the Predicted Probability of Each Alternative (Model 5A)





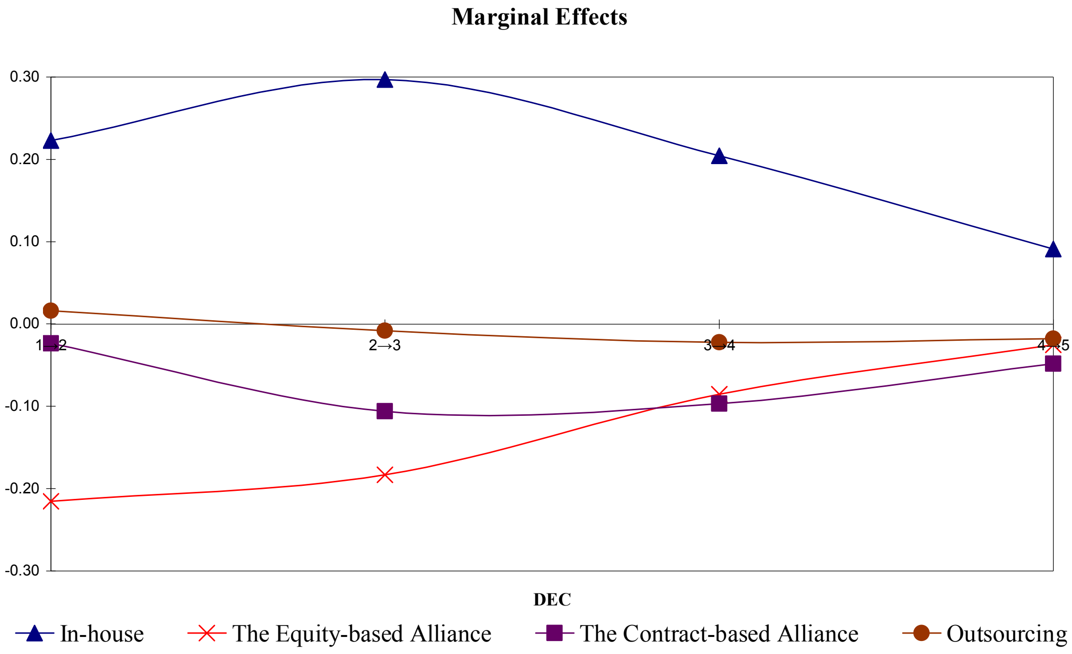
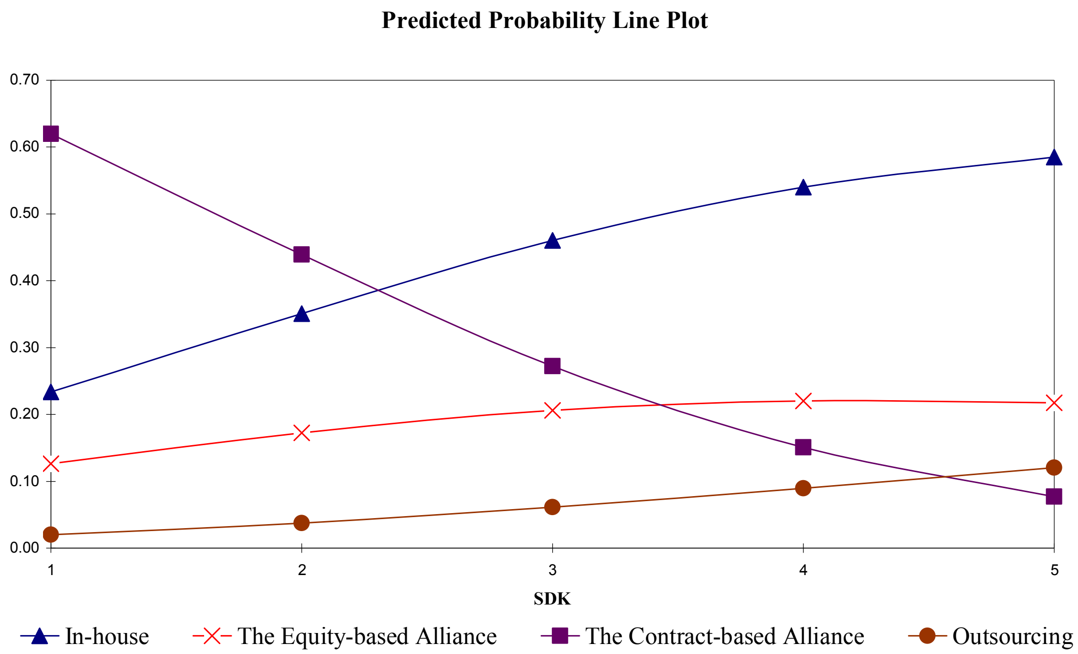
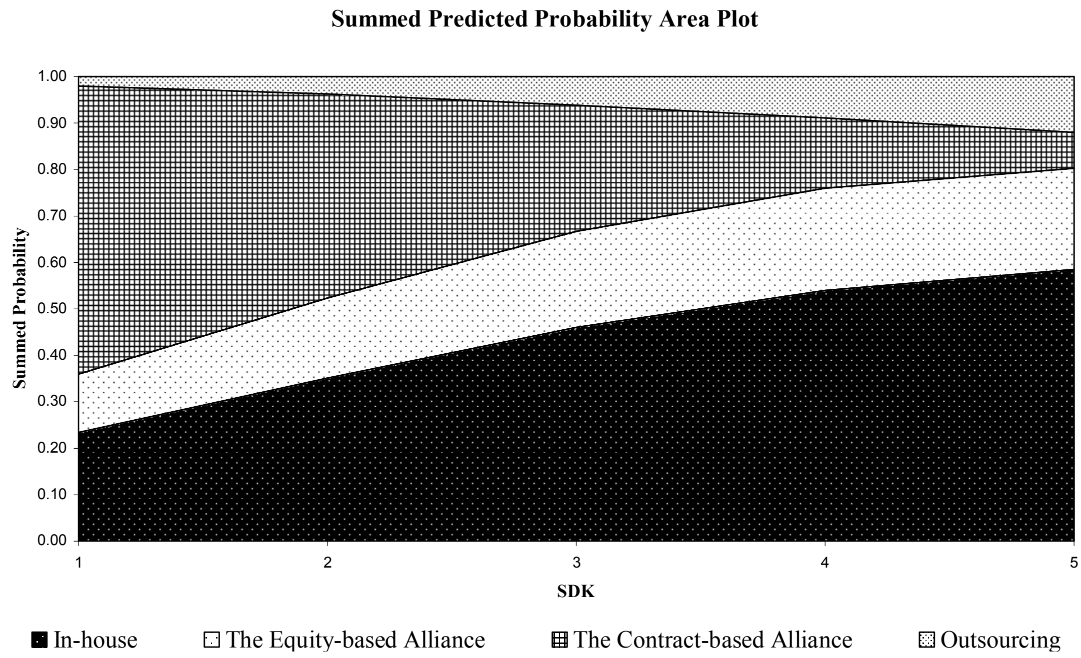
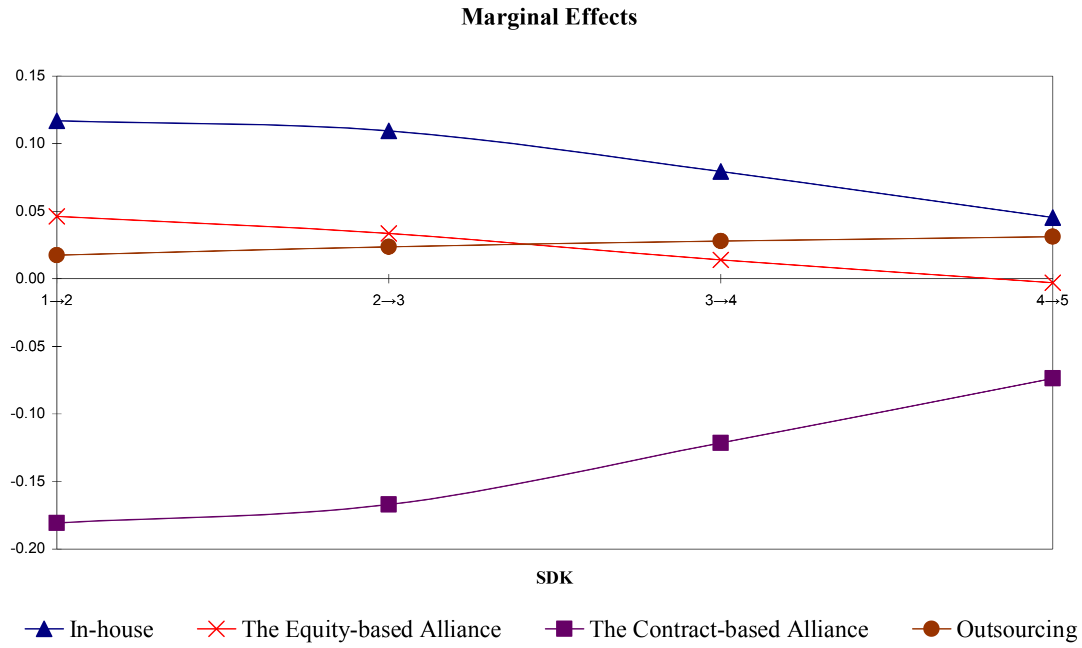


Figure 6-4-8 indicates that the probability of choosing in-house increases monotonically with respect to DEC. This comes almost exclusively through the reduction in the probabilities of choosing both types of alliance. Although DEC's impacts on the two types of alliance are of the same pattern, on average, its effect on the equity-based alliance is seemingly stronger than on the contract-based alliance. Finally, similar to that in model 4B, DEC has very little impact on the probability of choosing outsourcing.

Figure 6- 4- 9: The Effects of the Point-by-Point Increase of SDK on the Predicted Probability of Each Alternative (Model 5A)

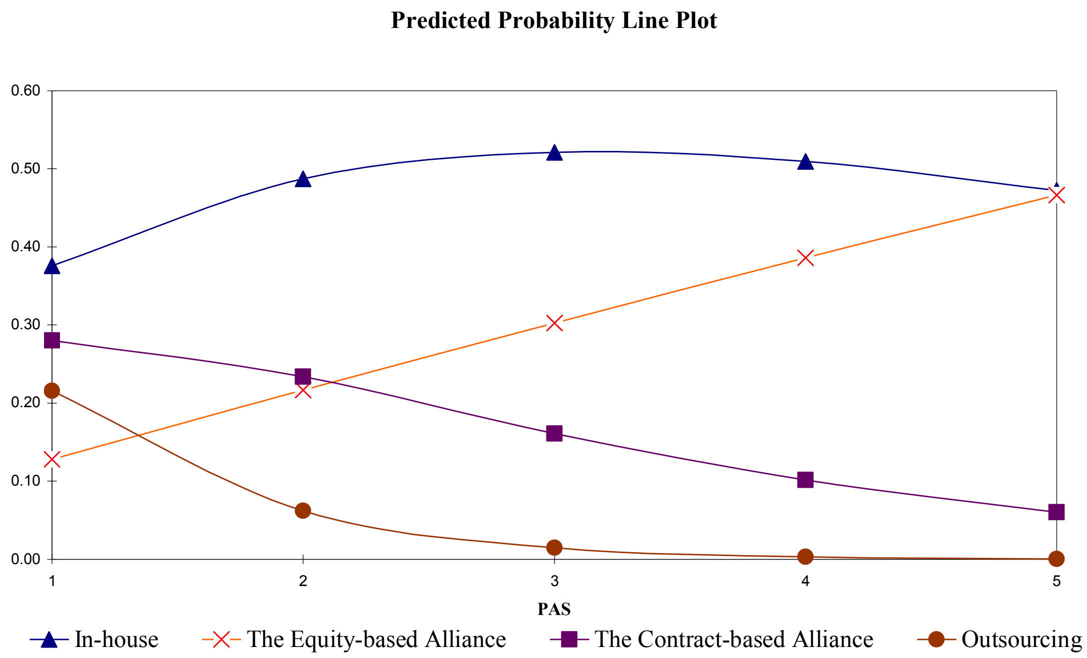


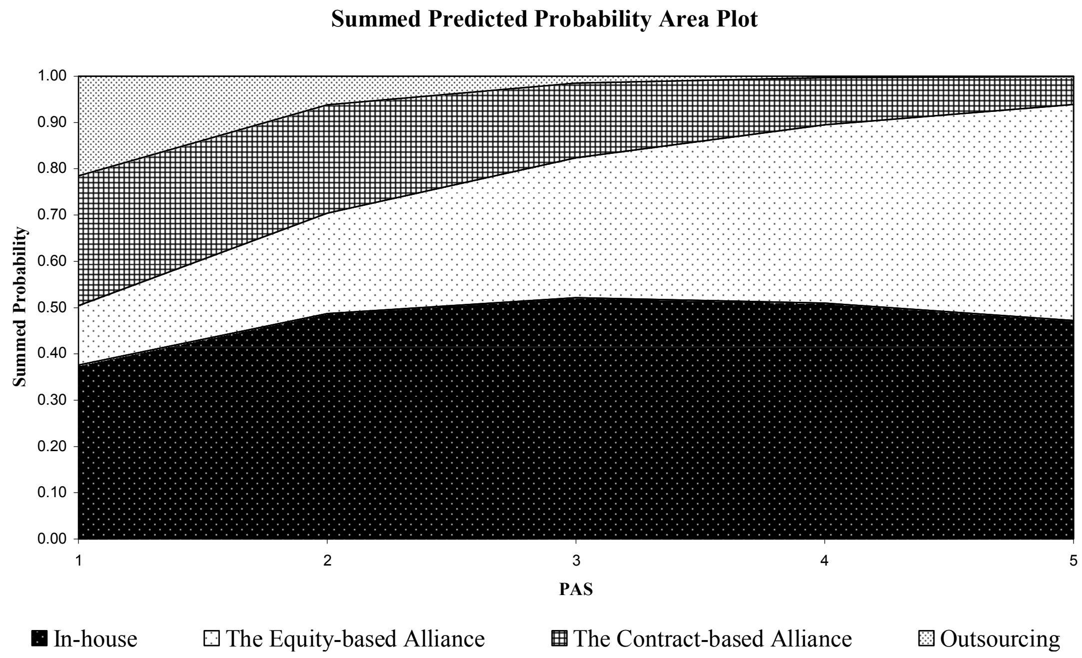




As shown in Figure 6-4-9, SDK's impacts on the predicted probabilities of the two types of alliance are in the opposite directions. Specifically, a higher SDK value tends to slightly increase the predicted probability of choosing the equity-based alliance; on the other hand, it significantly reduces the probability of choosing the contract-based alliance. Moreover, Figure 6-4-9 also suggests that the probability of choosing in-house increases with SDK in a monotonic fashion. Overall, the results tend to suggest, to mobilize socially distributed knowledge, some sort of hierarchical structure and equity-based arrangement are often needed, be it a pure internal hierarchy, or other equity-based arrangements. Therefore, a R&D project that involves highly socially distributed knowledge (indicated by a high value of SDK) is most likely to be organized internally.

Figure 6- 4- 10: The Effects of the Point-by-Point Increase of PAS on the Predicted Probability of Each Alternative (Model 5A)





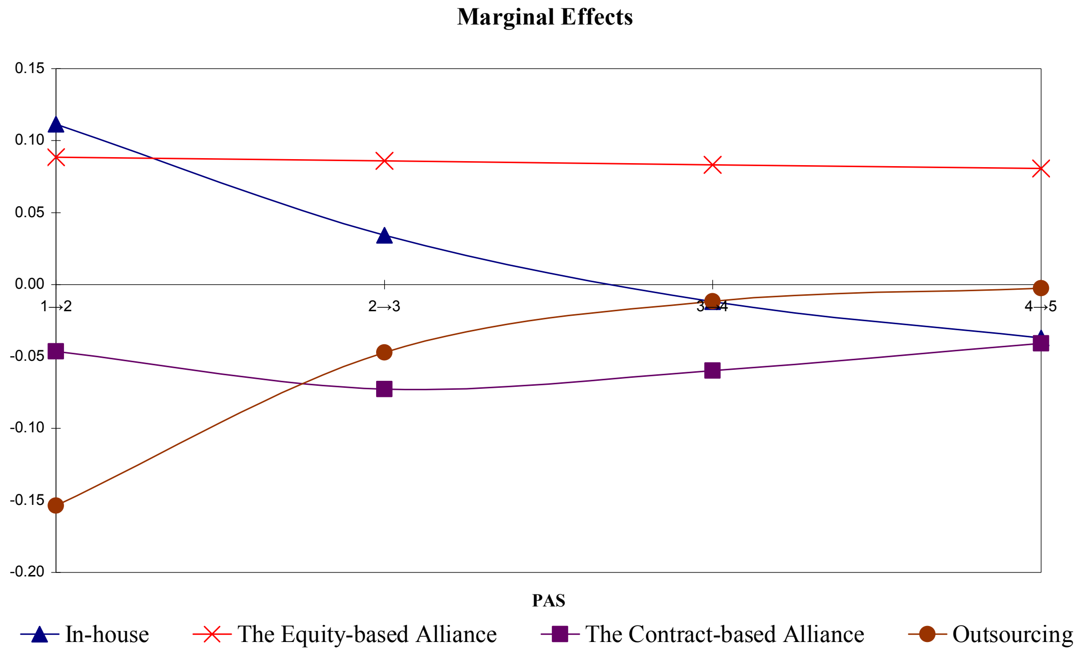
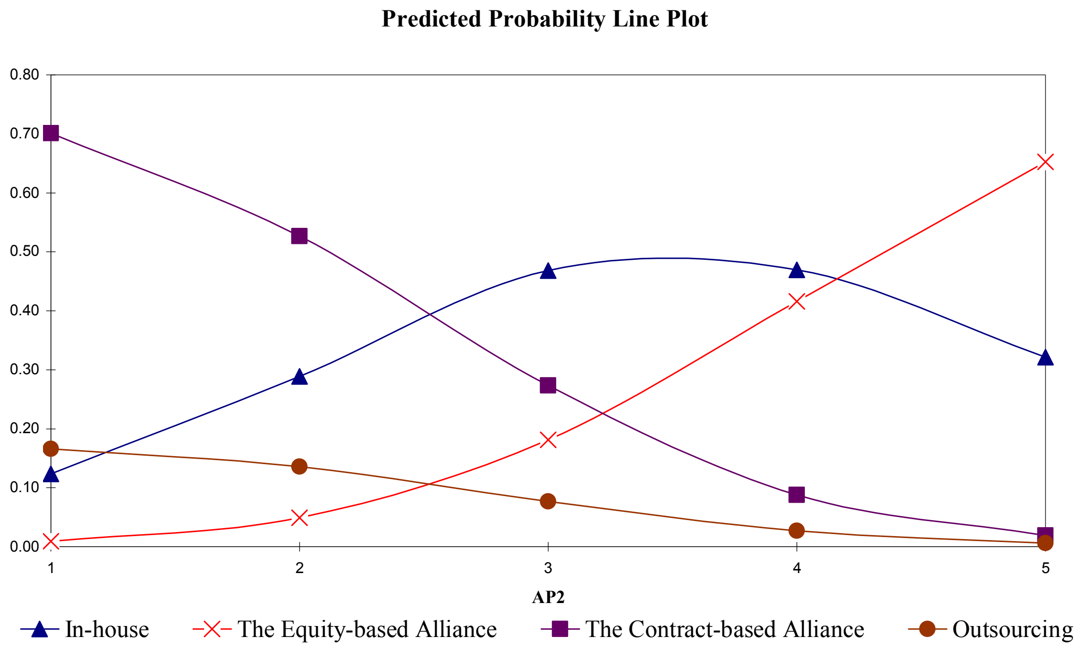
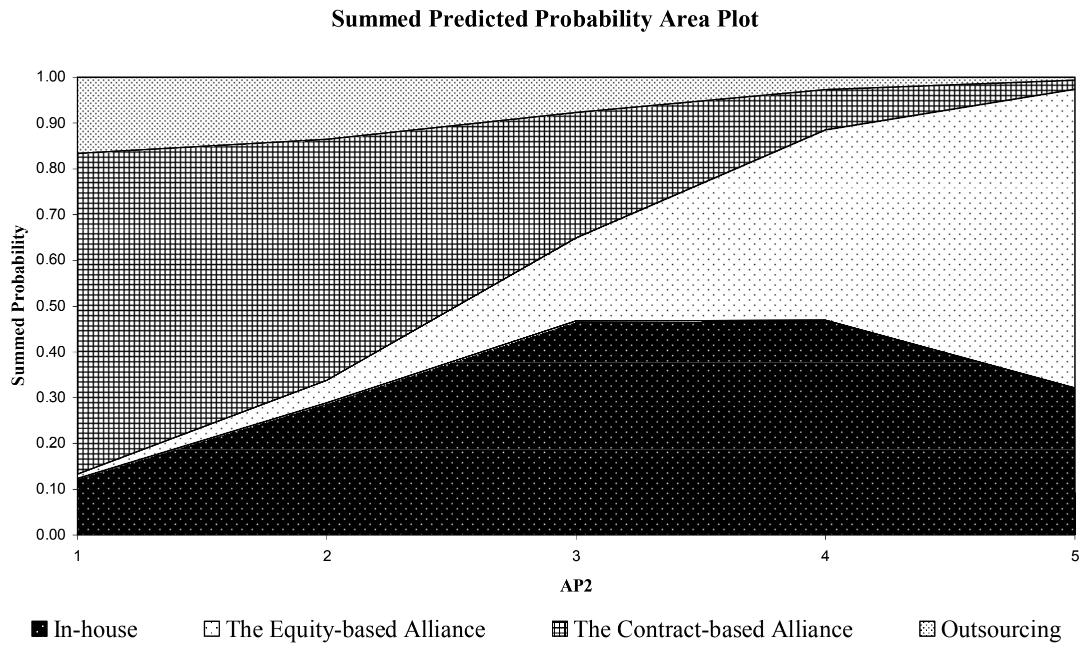
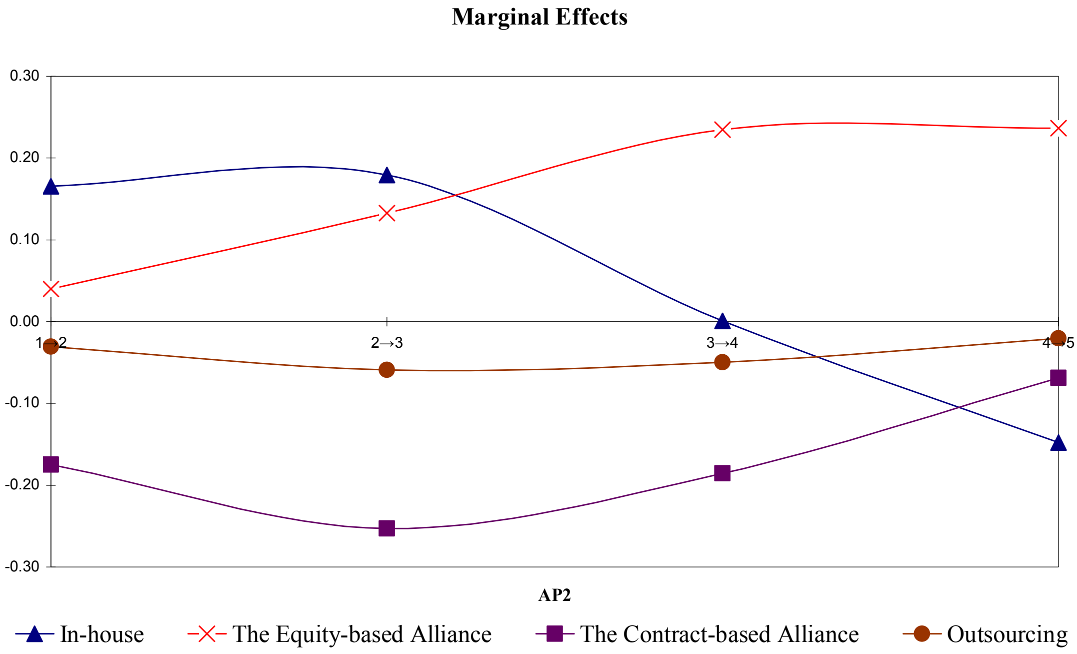


Figure 6-4-10 suggests, the increase in PAS tends to favour the choice of in-house and equity-based alliance but discourage the choice of the contract-based alliance and outsourcing. It is worth noting that PAS's impacts on the two types of alliance are in two directions, reminding us again that there are some crucial distinctions between the two types of alliance, and it might not be appropriate to put the two types of alliance in the same category. On the theoretical side, the very different performance of the two types of alliance in the face physical asset specificity can be related to their differences in incentive intensity, dispute settlement and administrative controls (Williamson, 1991). Following transaction costs reasoning, it has been argued that with the support of shared ownership, equity-based alliances provide superior incentive alignment and better administrative controls that help overcoming the problem of asset specificity in a more effective manner than contract-based alliances (E. Anderson & Gatignon, 1986; T. K. Das & Teng, 1996; Kogut, 1988b; Gary P. Pisano, 1989). Our result tends to support this view.

Figure 6- 4- 11: The Effects of the Point-by-Point Increase of AP2 on the Predicted Probability of Each Alternative (Model 5A)







Being another TCE variable, the pattern of AP2's marginal effects for the four alternatives shares some similarities with that of PAS. Specifically, a higher AP2 value (indicating a higher degree of appropriability) tends to increase the probabilities of choosing in-house and equity-based alliance, while it reduces the probability of choosing the other two alternatives. Moreover, AP2's marginal effects for the two types of alliance are also in the opposite direction—for the former, it is positive, and for the latter, it is negative. In short, the results tend to support the view that in-house and equity-based alliance are more effective in dealing with the problem of appropriability than contract-based alliance and outsourcing (Kogut, 1988b; Mowery et al., 1996b; Oxley, 1997; Oxley & Sampson, 2004; Oxley & Wada, 2009; Teece, 1986), we believe the underlying mechanisms are roughly the same as what we just mention above.

Finally, we observe that in Figure 6-4-11, the predicted probability of choosing in-house in not strictly increasing with respect to AP2[92]. In particular, when the value of AP2 changes from 4 to 5, the probability of choosing in-house even drops by a considerable 15 percentage points (down from 46.9% to 32.1%), making equity-based alliance two times more likely than in-house (65.3% vs. 32.1%) to be chosen as the organization mode for R&D projects that involve highly appropriable knowledge. In our view, this result is at odds with the prediction of transaction cost theory, since hierarchy (internal organization)—without any doubt—is generally

[92] A similar pattern also applies to PAS. However, in the case of PAS, at high value of PAS, in-house (rather than equity-based alliance) is still the dominant choice.

deemed by TCE as the most effective organization mode for dealing with the problem of appropriability. Meanwhile, this result is also hard to justify from the knowledge-based perspective.

Diagnostics and Testing

A final step for this section of analysis is to perform some diagnostic tastings on the estimation results. In particular, we are concerned about whether it is statistically justifiable to differentiate alliances into two categories. A dual formulation to the problem is to test whether the two categories could be combined. If all the coefficients for these two categories jointly do not differ from each other (in other words, the differences of all the corresponding pairs of coefficients are not statistically different form zero), it could be inferred that none of the independent variables significantly affects the relative probability of these two outcomes. Put differently, these two outcomes are indistinguishable with respect to the variables in the model (Long & Freese, 2006). In this case, these two categories can be combined.

We conduct both likelihood-ratio tests and Wald tests for combining outcome categories, the null hypothesise being that:

H_0: *The differences of all coefficients (except intercepts) associated with given pair of outcomes are 0 (i.e., categories can be collapsed).*

The results of the tests are given as follows (Table 6-4-16):

Table 6- 4- 17: Results of LR and Wald Tests for Combining Outcome Categories

LR Tests			
Categories tested	**chi2**	**df**	**P>chi2**
2-3	18.170	12	0.111
2-4	22.267	12	0.035
2-1	18.190	12	0.110
3-4	21.097	12	0.049
3-1	28.979	12	0.004
4-1	32.411	12	0.001
Wald Test			
Categories tested	**chi2**	**df**	**P>chi2**
2-3	25.477	12	0.013
2-4	38.679	12	0
2-1	24.406	12	0.018
3-4	38.500	12	0
3-1	51.346	12	0
4-1	70.667	12	0

The results of Wald test suggests, for all combinations of categories, the null hypothesis can be rejected ($p<0.10$). In other words, the differences for all the corresponding pairs of coefficients are statistically different from zero, therefore, no categories should be combined.

The LR test, on the other hand, gives different results. Specifically, for the two types of alliance with which we are most concerned, the result indicates that the null hypothesis cannot be rejected, but the *p* value is on the verge of significance ($p=0.111$). A similar case applies to the two categories of in-house and the equity-based alliance (null hypothesis cannot be rejected, but $p=0.11$). For all other combinations of categories, the LR test suggests that the null hypothesis can be rejected. In a nutshell, the LR test results suggest that the two pairs of categories (the equity-based alliance & the contract-based alliance, in-house & the equity-based alliance) can possibly be collapsed, but the corresponding *p*-values are all on the verge of significance.

Moreover, the above results are somewhat self-contradictory. Apart from the fact that LR and Wald tests give different results, one should also note that LR test suggests (1) we cannot reject that the two types of alliance are indistinguishable; and (2) we cannot reject that in-house and equity-based alliance are indistinguishable; but at the same time, (3) we can reject the hypothesis that contract-based alliance and in-house are indistinguishable. According to (1), it is justifiable to combine the two types of alliance; and according to (2), it is also justifiable to combine in-house with equity-based alliance. But the problem is—if we simultaneously combine the three categories, then the implication of (3) will certainly be violated. Therefore, if we have to make choice, it is probably safer only to combine the two types of alliance (whose p value is slightly greater than that for the other pair of categories).

Taking all the evidence into consideration, it is fair to conclude that, on an overall level and from an econometric point of view, the evidence tends to lend slightly more supports for (rather than against) the further differentiation of the two types of alliance, but it might not be conclusive enough.

To make sure that the MNL is the right model, we also conduct the Hausman test of IIA assumption on the basis on the Model 5A. The null hypothesise being that:

H_0: *Odds (outcome-J vs. outcome-K) are independent of other alternatives.*

The results of tests are shown in Table 6-4-17.

The results of the test suggest that in the new model of 5A, the null hypothesis of independence of irrelevant alternatives cannot be rejected. In other words, we found no evidence that the odds are influenced by the numbers of categories present. This means, the choice of MNL is appropriate.

Table 6- 4- 18: Results of Hausman Tests of IIA Assumption (Model 5A)

Omitted	chi2	Df	P>chi2	evidence
1	0.621	26	1.000	for H_0
2	2.829	26	1.000	for H_0
3	-1.519	26	1.000	for H_0
4	5.339	26	1.000	for H_0

Note: If chi2<0, the estimated model does not meet asymptotic assumptions of the test.

6.5 Conclusions

Using a small dataset (142 cases) collected by questionnaire from the Chinese Consumer Electronics industry, we empirically test in this chapter some problem solving perspective hypotheses alongside other competing views (e.g., the transaction cost economics) in a series of binomial and multinomial models to examine the relative explanatory power of the problem solving perspective. Overall, our results are seemingly more supportive of the problem solving perspective rather than the transaction cost economics. Below, we summarize the main findings of our econometric analyses (see table 6-5-1). A more detailed discussion will be left for the next chapter.

Table: 6- 5-1: Comparing Hypotheses and Empirical Results

Variable	*Predicted Sign (Binary Probit)*			*Estimated Results (Binary Probit)*			*Predicted Sign (Multinomial logit, 3 Alternatives, In-house as base)*		*Estimated Results (Multinomial logit, 3 Alternatives, In-house as base)*		*Predicted Sign (Multinomial logit, 4Alternaitves, In-house as base)*			*Estimated Results (Multinomial logit, 4 Alternatives, In-house as base)*		
	I. vs. A. (I.=1)	I. vs. O. (I.=1)	A. vs. O. (A.=1)	I. vs. A. (I.=1)	I. vs. O. (I.=1)	A. vs. O. (A.=1)	A.	O	A.	O.	EBA	CBA	O.	EBA	CBA	O.
PS 1→5 Well-Structured → Ill-Structured	+	+	+	-	+(**)[93]	+(#)[94]	-	-	+	-	-	-	-	+	+	-
COM 1→5 Simple → Complex	+	+	+	-(**)	+(**)[95]	+(***)	-	-	+(**)	-	-	-	-	+(**)	+	-
DEC 1→5 Decomposable → Non-Decomposable	+	+	+	+(***)	+(**)[96]	-	-	-	-(**)	-	-	-	-	-(**)	-(*)	-
EKB 1 → 5 Little Knowledge → Complete Knowledge	+	+	+	+(***)	+(***)	+(***)	-	-	-(***)	-(***)	-	-	-	-(***)	-(***)	-(***)
COD 1 → 5 Codifiable → Non-Condifiable	+	+	(?)	+	-	-	-	-	-	+	-	-	-	-	+	+
TEA 1 → 5 Teachable—Non-Teachable	+	+	(?)	-	+	+	-	-	+	-	-	-	-	-	+	-

[93] Model 2A.
[94] On the verge of significance.
[95] Model 2C.
[96] Model 2D.

SDK **1 → 5** **Non socially-distributed (personal) → Highly socially distributed**	+	+	(?)	+(*)	-	-	-	-	-(*)	+	-	-	-	-	-(***)	-
DU **1 → 5** **low demand uncertainty → high demand uncertainty**	+	+	(?)	+	-	-	-	-	-	+	-	-	-	-	-	+
HAS **1 → 5** **Low human asset specificity → high human asset specificity**	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
PAS **1 → 5** **Low physical asset specificity → high physical asset specificity**	+	+	+	+	+(**)	+(#)	-	-	-	-(**)	-	-	-	+	-	-(**)
AP1 **1 → 5** **Non-appropriable → highly appropriable**	+	+	+	-	-	+	-	-	+	+	-	-	-	+	+	+
AP2 **1 → 5** **Non-appropriable—highly appropriable**	+	+	+	+	+(*)	+	-	-	-	-	-	-	-	+(*)	-(**)	-(*)

Note: Sign of the coefficients are based on the full model which includes all the explanatory variables. Significance levels of the estimated coefficients are based on the more parsimonious (simplified) model obtained through models selection process in each circumstance.

For the choice of in-house vs. outsourcing, each of the three complexity-related variables is seemingly equally valid in capture the effect of complexity. Statistically, it is justifiable to combine the three variables into a single new construct AVECOM (defined as the average of the three complexity-related variable), the new composite variable AVECOM is significant at the level of 1% both in the full model and the simplified models

(1) Complexity, Decomposability and Problem structure

As the study is primarily inspired by the problem-solving perspective in the knowledge-based view, we are particular interested in the effects of the few PSP variables. In this study, we include all the three variables and test their effects simultaneously. Our estimation results suggest that the effects of problem complexity and decomposability are significant for many of the organizational choices; while the effects of problem structure are less evident as it only plays a role for the choice between in-house and outsourcing.

To be more exact, in the binomial estimations, it is found that as the far as the choice of in-house vs. outsourcing is concerned, each of the three complexity-related variables is as good as the others (significant at the level of 5%) in capturing the effects of problem solving complexity. This result is confirmed by testing the equality of the coefficients of the three variables, and it is further found that if we replace them with a new composite construct AVECOM (defined as the average of PS, COM and DEC), the coefficient of the new variable is even more significant (at the level of 1%) and the goodness-of-fit of the new model is better as well. On the whole, the above results suggest that an increase in any of the three complexity-related variables—be it problem structure, complexity or decomposability—tends to favour the choice of in-house over outsourcing, and their effects are hard to be differentiated from one another.

Apart from the choice between in-house and outsourcing, the effects of decomposability and complexity are also significant for some other binary choice. Specifically, complexity (COM) is estimated to be significant for all the other two organizational choices (in-house vs. alliance and alliance vs. outsourcing), and decomposability (DEC) is significant for the choice between in-house and alliance. To be more exact, when the choice is made between in-house and alliance, it is found that—somewhat contrary to the general PSP prediction—an increase in complexity (COM) tends to (significant at the level of 5%) increase the probability of choosing alliance over in-house; while for the choice between alliance and outsourcing, an increase in complexity will significantly (at the level of 1%) increase the probability of choosing alliance over outsourcing—as it is predicted by the theory. The effect of decomposability is also significant for the choice of in-house vs. alliance, but the effect for this variable—which is generally regarded as a subordinated dimension of complexity—is in the ***opposite*** direction as that for COM. Specifically, a higher DEC value tends to favour the choice the in-house rather than alliance (significant at the level of 1%).

Multinomial logit estimations produce very similar results. When the dependent variable is treated as a trinomial variable, the coefficients for COM and DEC are estimated to be significant (both at the level of 5%) for the alternative of alliance (in-house being the baseline), but with different signs. When the two types of alliance (equity-based vs. contract-based) are further differentiated and the *dependent* variable is treated as a variable with four *response* categories (in-house being the baseline category), it is found that the positive coefficient for COM is significant (at the level of 5%) for equity-based alliance but not for contract-based alliance, while the negative coefficient of DEC is significant for both types of alliance. These results tend to suggest—as the complexity of the problem becomes higher, alliance in general and equity-based alliance in particular is more likely to be chosen over in-house, while a higher degree of decomposability will make both types of alliance less likely to be chosen over in-house.

On the whole, this study produces mixed results. On the one hand, our results tend to support the PSP argument that when the choice is made between make or buy, in-house is more effective for solving ill-structured, complex and non-decomposable problems, while market modes of organization realize performance advantages when the problem is well-structured, simple and decomposble (Nickerson & Zenger, 2004; Macher, 2006; Macher & Boerner, 2011). Moreover, our results are also supportive of the PSP argument that among various alliance forms, the more hierarchical equity-based alliance (e.g. joint venture) is more likely to be chosen over contract-based alliance when problem-solving complexity is higher (Heiman & Nickerson 2004).

On the other hand, our results are at odds with some widely held PSP beliefs. For example, in the PSP, it is generally (though implicitly) held that as far as their impacts on governance choices are concerned, the effects of problem complexity and decomposability move in the same direction (Nickerson & Zenger, 2004). Moreover, the PSP tend to believe that internal organization is more efficient in dealing with highly complex problems, whereas alliances are appropriate for solving moderately complex problems (Leiblein & Macher, 2009). Our results, by contrast, reveal that the effects of COM and DEC move in two directions when the choice of in-house vs. alliance is considered. Specifically, a higher level of complexity tends to favour the choice of alliance, suggesting that alliance is more efficient for solving more complex problems; whereas a higher DEC value (i.e., more difficult to be decomposed) tends to favour the choice of in-house, meaning that internal organization is better able to deal with non-decomposable problems.

(2) A Firm's Existing Knowledge Base

In this research, we include a firm's "absolute knowledge base" as an explanatory variable. Overall, our estimation results indicate that a firm's existing knowledge-base is the ***most powerful single explanatory variable***, as its effects are persistently significant (mostly at the level of 1%) for all the organizational choices we examine. To be more exact, it is found that when a firm is confronted with a problem for which it has a sufficiently high level of relevant knowledge, the firm tend to organize the problem solving internally, ceteris paribus. If, on the contrary, a firm has very little background knowledge in relevant fields, the firm tends to choose outsourcing as the organizational mode. Between these two polar situations, alliances are most likely to be chosen, with the contract-based alliance being more preferred. Put somewhat differently, these results tend to suggest, in terms of their respective requirement for knowledge-base, in-house is the most demanding among these three types of organizational mode, outsourcing demands least knowledge-base, and alliances typically demand a medium level of knowledge-base.

Generally speaking, our results are in line with the insights and the bulk of empirical evidence in the RBV literature (Argyres, 1996; Bigelow & Argyres, 2008; Jacobides & Hitt, 2005; Madhok, 2002; Poppo & Zenger, 1998; Qian et al., 2009; G. Walker & Weber, 1984) which indicate clearly that a firm's existing knowledge base has a strong independent effect on its organizational choice.

(3) Knowledge Tacitness and Social Distribution

In this research, tacitness and social distribution of knowledge are simultaneously included as explanatory variables. The estimation results show that knowledge tacitness is not significant for any of the choices. This result is at odds with most of the existing studies that investigate the governance implications of knowledge tacitness (C.-J. Chen, 2004; Heiman & Nickerson, 2004; Kogut & Zander, 1993; Mowery et al., 1996b; Shenkar & Li, 1999), but it does not come as a complete surprise, as at least one previous study (Clarke et al., 2008) comes to a similar conclusion.

By contrast, ***social distribution (embeddedness) of knowledge*** (hereafter *SDK*) is estimated to be a significant determinant for some of the organizational choices. To be more exact, in the binomial estimations, *SDK* is estimated to be significant (at the level of 10%) for, and only for, the choice between in-house and alliance. When the dependent variable is treated as a trinomial variable, it is estimated that an increase in *SDK* will significantly (at the level of 10%) reduce the probability of choosing alliance over in-house. While when the organizational choice is to be made from the four alternatives, it is estimated that an increase in *SDK* significantly (at the level of 1%) reduces the possibility of choosing the contract-based alliance over in-house; for equity-based alliances, the impact of an increase in *SDK* is in the same direction as that for contract-based alliances, but the effect is far from being significant.

The above results tend to suggest, the more socially distributed the knowledge is, the more likely that internal organization will be chosen as the governance mode. Moreover, it is also suggested that of the two categories of alliance, contract-based alliance is particularly not suitable for mobilizing socially distributed knowledge. Overall, these results are roughly consistent with the “received wisdom” of the theoretical literature (Hippel, 1994; Langlois, 1992; Langlois & Foss, 1999) as well as the findings of the limited empirical studies (e.g., Heiman & Nickerson, 2004) which generally held that socially distributed knowledge favours the choice of internal organization; and that when the choice is to be made between the two forms of alliance, equity-based alliances are more effective vehicles than contract-based alliances for mobilizing socially distributed knowledge.

(4) Transaction costs variables: Physical Asset Specificity (PAS), Human Asset Specificity (HAS), Demand Uncertainty (DU) and Appropriability (AP1, AP2)

To compare the relative explanatory power the problem solving perspective and the now dominant transition cost economics theory, we include in this research a few transition cost variables. Our estimation results indicate that, either in terms of the magnitude of effect, or in terms of the level of significance, the relative explanatory power of transaction cost economics is less evident than that of that of the problem solving perspective. Specifically, in the binomial estimation, it is found that PAS (at the level of 5%) and AP2 (at the level of 10%) are significant for (and only for) the choice between In-house vs. outsourcing. This seems to suggest, transaction costs considerations, such as appropriability hazard and physical asset specificity, are among the factors that would have a significant impact on the organizational choice of the R&D activities. While for other binary choice, (e.g., the choice if in-house vs. alliance), transaction costs considerations are far less decisive. Multinomial estimations produce similar results. Interestingly, when the *dependent* variable is treated as a variable with four *response* categories, it is found that the coefficient of AP2 are significant for all of choices (in-house being the baseline), however, for the alternative (equity-based alliance), the sign of the estimated coefficient of AP2 is at odds with the theoretical prediction, and we find it difficult to explain this result.

Summing up, it seems fair to conclude that each of the theoretical perspective receives some partial support from our results, but in general, the evidence is more supportive of the problem solving perspective rather than the transaction cost economics.

Chapter 7: Comments on Our Results and Conclusions

This chapter consists of three sections. In section 1, we compare our results with those of the relevant existing literature, and then make some comments. In section 2, we discuss the limitations of our research. In section 3, we highlight the key contributions of the thesis and make some concluding remarks.

7.1 Comment on our Results

On the basis of a detailed review of relevant empirical literature presented in Chapter 5, we now compare our results with those of the relevant existing literature.

7.1.1 Complexity, Decomposability and Problem structure.

In the problem solving perspective literature, it is generally recognized that problem structure, problem complexity and decomposability are the few critical dimensions indicative of problem solving complexity. In this study, we include all the three variables and test their effects simultaneously. What is worth mentioning, is that in previous studies, the effects of problem complexity and decomposability are not specifically differentiated—or to be more exact, problem decomposability is often treated as a subordinate characteristic of problem complexity; while in this study, complexity and decomposability are treated as two related but analytically distinct variables and we try to empirically differentiate their respective effects.

Overall, our estimation results suggest that the effects of problem complexity and decomposability are significant for many of the organizational choices; while the effects of problem structure are much less evident and it seems that it plays a role only for the choice between in-house and outsourcing.

To be more exact, in the binomial estimations, it is found that as the far as the choice of in-house vs. outsourcing is concerned, each of the three complexity-related variables is equally valid (significant at the level of 5%) in capturing the effects of problem solving complexity. Having tested the equality of the three coefficients, we replace them with a new composite construct AVECOM (defined as the average of PS, COM and DEC), it is further found that the coefficient of the new variable is even more significant (at the level of 1%) and the goodness-of-fit of the new model is better as well. On the whole, the above results suggest that an increase in any of the three complexity-related variables—be it problem structure, complexity or decomposability—tends to favour the choice of in-house over outsourcing.

The effects of decomposability and complexity are also significant for more binary choices. Apart from the choice between in-house and outsourcing, complexity (COM) is estimated to be significant for all the other two organizational choices (in-house vs. alliance and alliance vs. outsourcing), and decomposability (DEC) is significant for the choice between in-house and alliance. To be more exact, when the choice is made between in-house and alliance, it is found that—somewhat contrary to the general prediction—an increase in complexity (COM) tends to (significant at the level of 5%) increase the probability of choosing alliance over in-house; while for the choice between alliance and outsourcing, an increase in complexity will significantly (at the level of 1%) increase the probability of choosing alliance over outsourcing. The effect of decomposability is also significant for the choice of in-house vs. alliance, and we note that the effect for this variable—which is generally regarded as a subordinated dimension of complexity—is in the same direction as that for COM. Specifically, a higher DEC value tends to favour the choice the in-house rather than alliance (significant at the level of 1%).

Multinomial logit estimations produce very similar results. Specifically, when the dependent variable is treated as a trinomial variable, the coefficients for COM and DEC are estimated to be significant (both at the level of 5%) for the alternative of alliance (in-house being the baseline), and with different signs—for COM, the coefficient is positive, while for DEC, the coefficient is negative. When the two types of alliance (equity-based vs. contract-based) are further differentiated and the *dependent* variable is treated as a variable with four *response* categories (in-house being the baseline category), it is found that the positive coefficient for COM is significant (at the level of 5%) for equity-based alliance but not contract-based alliance, while the negative coefficient of DEC is significant for both types of alliance.

Putting together the information in the above paragraph, our results tend to suggest—as the complexity of the problem becomes higher, alliance in general and equity-based alliance in particular is more likely to be chosen over in-house, while a higher degree of decomposability will make both types of alliance less likely to be chosen over in-house. In other words, the results indicate that compared with internal organization, equity-based alliance is more preferred for solving more complex problems, but is less preferred for solving non-decomposable problems.

In light of the general predictions of the relevant theoretical literature (Heiman & Nickerson, 2002; Heiman et al., 2009; Leiblein & Macher, 2009; Nickerson et al., 2007; Nickerson & Zenger, 2004), and the findings of the limited empirical studies

(Heiman & Nickerson, 2004; Leiblein et al., 2009; Macher, 2006; Macher & Boerner, 2011; Phene & Tallman, 2012), our study produces mixed results. On the one hand, as summarized above, our results tend to support the argument that when the choice is made between make or buy, in-house is more effective for solving ill-structured and complex problems, while market modes of organization realize performance advantages when the problem is well-structured and simple (Nickerson & Zenger, 2004; Macher, 2006; Macher & Boerner, 2011). In addition, our results are also supportive of the argument that among various alliance forms, the more hierarchical equity-based alliance (e.g. joint venture) is more likely to be chosen over contract-based alliance when problem-solving complexity is higher (Heiman & Nickerson 2004), or when the need for coordination is greater (Leiblein et al., 2009; Phene & Tallman, 2012).

On the other hand, we also note that some of our results are at odds with certain widely held PSP arguments (indeed, beliefs). For example, in the PSP, it is generally (and implicitly) believed that as far as the impact on governance choice is concerned, the effects of problem complexity and decomposability would move in the same direction (Nickerson & Zenger, 2004). Moreover, some theorists also believe that alliances are sorts of hybrid modes lying somewhere between internal organization (hierarchy) and arm's-length market contract; accordingly, they argue that internal organization is more efficient in dealing with highly complex problems, whereas alliances are more appropriate for solving moderately complex problems (Leiblein & Macher, 2009). Our results, by contrast, reveal that the effects of COM and DEC move in two directions when the choice of in-house vs. alliance is considered. Specifically, a higher level of complexity tends to favour the choice of alliance, suggesting that alliance is more efficient for solving more complex problems; whereas a higher DEC value (i.e., more difficult to be decomposed) tends to favour the choice of in-house, meaning that internal organization is better able to deal with non-decomposable problems.

Nevertheless, we don't think the above results are incompatible with the basic logic of the knowledge-based view and the problem-solving perspective. In particular, we note that in the literature, the theoretical predictions made by some other knowledge-based proponents (Coombs & Metcalfe, 2000; Grant & Baden-Fuller, 2004) are roughly in line with our results. For example, Coombs and Metcalfe (2000) argue that in a world of increasing technological complexity, it is less likely that the knowledge/capabilities required for certain fundamental innovations are readily located within a single firm; rather, they are often distributed/dispersed across a range of firms and other knowledge generating institutions. Such innovations require coordination of existing capabilities and, possibly, the generation of new capabilities through novel combination. Accordingly, the firms refer more often to various cooperative arrangements for accomplishing such 'distributed innovation processes'. To rephrase, the essence of their argument is that firms increasingly rely on various collaborative arrangements to access capabilities/knowledge which they do not possess but nevertheless are required for solving a highly complex problem that internal organization simply isn't able to cope with. It is also worth noting that their definition of complexity is highly compatible with that of ours. Specifically, they define complexity of a innovation in terms of the following three aspects: (1) technological diversity—i.e., the range of constituent technologies and knowledge bases; (2) systematic complexity—i.e., the need to coordinate between different technological interfaces of the constituent technologies/knowledge; and (3) technological connectedness—i.e., on the one hand, the interconnections among different scientific disciplines (technological fields) are increasingly more extensive and more intensive; on the other hand, each scientific discipline and technological field tends to be more specialized.

On the empirical side, we note that some recent studies produce results similar to ours. For example, Bonesso, Comacchio and Pizzi (2011) explore how the breadth of knowledge required to undertake a NPD (new product development) project might affect a firm's choice between internal vs. external technology sourcing. It is found that, the higher the knowledge breadth that is required to undertake a NPD project[1], the more likely that a firm will refer to external technology sourcing, of which cooperative R&D arrangements are important options.

As a final remark for this section of discussion, we would like to repeat our observation that as an emerging perspective, much more conceptual, theoretical, and empirical research is needed if the problem-solving perspective is to be developed into a full-fledged theory of the firm. In particular, we note that empirical studies regarding how the different dimensions of problem-solving complexity might affect the choice of alliance governance are seriously underdeveloped—in fact, we don't even know to what extent these different "hybrid" organizational arrangements are really hybrid in terms of their problem solving costs and competencies.

[1] Note that we define complexity by two dimensions: the number of the knowledge sets required to undertake a productive activity, and the degree of interactions between these knowledge sets. Therefore, their result is at least partially consistent with ours.

7.1.2 A Firm's Existing Knowledge Base

In this research, we include a firm's "absolute knowledge base" (as compared to the "relative knowledge base") as an explanatory variable. As our data is collected at the project-level, we adopt a project-level measure of a firm's existing knowledge base. Specifically, the measure (EKB) is defined as the extent to which a firm possesses all the relevant knowledge/capabilities that is required to solve the problem at the time of project initiation.

Overall, our estimation results indicate that a firm's existing knowledge-base is the most powerful single explanatory variable, as its effects are persistently significant (mostly at the level of 1%) for all the organizational choices we examine.

To be more exact, in the binomial estimations, it is found that as far as the choice of in-house vs. outsourcing is concerned, a higher level of existing knowledge favours the choice of in-house (significant at the level of 1%). When the choice is made between in-house vs. alliance, or alliance vs. outsourcing, a higher level of existing knowledge base tends to favour in-house and alliance respectively (significant at the level of 1%). Multinomial logit estimations produce highly consistent results in that either the sign, magnitude or the significance level of relevant coefficients is very much in line with the binomial estimations, no matter whether the dependent variable is treated as having three alternatives or four alternatives (with contract-based and equity-based alliances as separate alternatives).

Pulling together all these results, the message is, when a firm is confronted with a problem for which it has a sufficiently high level of relevant knowledge, it is most likely the firm will organize the problem solving internally, ceteris paribus. If, on the contrary, a firm has very little background knowledge in relevant fields, the firm tends to choose outsourcing as the organizational mode. Between these two polar situations, alliances are most likely to be chosen, with the contract-based alliance being more preferred. Put somewhat differently, these results tend to suggest, in terms of their respective requirement for knowledge-base, in-house is the most demanding among these three types of organizational mode, outsourcing demands least knowledge-base, and alliances typically demand a medium level of knowledge-base.

As noted in chapter 4, a firm's existing knowledge base has profound impacts not only on the performance, but also on the organizational choice of its problem solving activities, but the theme is underexplored in the existing problem-solving perspective literature.

In the existing PSP literature, Macher and Boerner (2012) did explore the organizational implications of a firm's knowledge base, but they focused mainly on its interaction effect with problem structure, and they were agnostic as to whether a firm's existing knowledge base has an independent impact on its organizational choice (i.e., they tended to treat such an effect as being neutral with respect to the make-or-buy decision).

Contrary to Macher and Boerner's (2012) view, but in line with the insights and the bulk of empirical evidence in the RBV literature (Argyres, 1996; Bigelow & Argyres, 2008; Jacobides & Hitt, 2005; Madhok, 2002; Poppo & Zenger, 1998; Qian et al., 2009; G. Walker & Weber, 1984), our results indicate clearly that a firm's existing knowledge base has a strong independent effect on its organizational choice of problem solving activities. To be more exact, our results tend to support RBV's general argument that (1) firms internalize activities in which they have greater experience and/or superior capabilities, and outsource those in which they have inferior capabilities, and that (2) a firm tends to refer to various collaborative arrangements to get access to complimentary knowledge/capabilities which they do not possess but which are necessary for solving a complex problem; our results also support the intuition that (3) in-house, alliance and outsourcing line up with regard to their respective knowledge-base requirement.

Finally, although we are particularly interested in the interaction effects between a firm's existing knowledge base and other variables (e.g., problem attributes and knowledge characteristics), we do not go further in that direction. The reason is twofold. Firstly, as noted in chapter 6, the econometric technique for examining the "interaction term" in the logit/probit models has been seriously challenged by some econometricians (Ai & Norton, 2003; Huang & Shields, 2000; Norton, Wang, & Ai, 2004), as it turns out that, unlike OLS, the coefficient of the interaction term in a probit/logit model does not tell us either the direction, magnitude, or the significance of the "interaction effect". Secondly, given the small sample nature of our dataset, the inclusion of more variables tends to make the model less conclusive. That being said, we think the following questions are of great interest and are promising avenues for future research—that is, given that a problem is sufficiently complex that the breadth of relevant knowledge goes well beyond a firm's existing knowledge base, how will the firm organize the solving of this problem? Will different problem attributes and knowledge characteristics have any impact on the firm's choice? And if so, how do these attributes interact with a firm's knowledge base and learning ability to determine its organizational choice? Up to now, these are basically open questions.

7.1.3 Knowledge Tacitness and Social Distribution

In this research, tacitness and social distribution of knowledge are simultaneously included as explanatory variables. Following Kogut and Zander (1993), knowledge tacitness is measured by the two dimensions of codifiability and teachability. The estimation results show that knowledge tacitness is not significant for any of the choices. This result is at odds with most of the existing studies that investigate the governance implications of knowledge tacitness (C.-J. Chen, 2004; Heiman & Nickerson, 2004; Kogut & Zander, 1993; Mowery et al., 1996b; Shenkar & Li, 1999), but it does not come as a complete surprise, as at least one previous study (Clarke et al., 2008) comes to a similar conclusion.

By contrast, ***social distribution (embeddedness) of knowledge*** (hereafter *SDK*) is estimated to be a significant determinant for some of the organizational choices. To be more exact, in the binomial estimations, *SDK* is estimated to be significant (at the level of 10%) for, and only for, the choice between in-house and alliance. Similarly, in the multinomial logit estimations, when the dependent variable is treated as a trinomial variable, it is estimated that an increase in *SDK* will significantly (at the level of 10%) reduce the probability of choosing alliance over in-house. And when the organizational choice is to be made from the four alternatives, it is estimated that an increase in *SDK* significantly (at the level of 1%) reduces the possibility of choosing the contract-based alliance over in-house; for equity-based alliances, the impact of an increase in *SDK* is in the same direction as that for contract-based alliances, but the effect is far from being significant.

The above results tend to suggest, the more socially distributed the knowledge is, the more likely that internal organization will be chosen as the governance mode. Moreover, it is also suggested that of the two categories of alliance, contract-based alliance is particularly not suitable for mobilizing socially distributed knowledge. Overall, these results are roughly consistent with the “received wisdom” of the theoretical literature (Hippel, 1994; Langlois, 1992; Langlois & Foss, 1999) as well as the findings of the limited empirical studies (e.g., Heiman & Nickerson, 2004) . In both literatures, it is generally held that socially distributed knowledge favours the choice of internal organization; and that when the choice is to be made between the two forms of alliance, equity-based alliances are more effective vehicles than contract-based alliances for mobilizing socially distributed knowledge.

At this end of this section, we would like to make some final comments. As we have shown above, in this research, it is estimated that knowledge tacitness is not a significant determinant for governance choices, while social distribution of knowledge is. This combination tends to suggest that knowledge tacitness, by itself, does not constitute a barrier to inter-firm knowledge transfer. Logically, tacit knowledge, even of a "cognitive type" (Balconi et al., 2007), could be personal knowledge—that is, it could be embedded in a single individual and be mobilized on a personal level to fulfil complex problem-solving activities. In this case, to get access to complementary knowledge, the firms don't have to refer to formal governance mechanisms (say, by setting up equity-based alliances); rather, they could hire expert knowledge workers in a well-functioning labor market. In fact, it has been noted (H. W. Chesbrough, 2003) that "learning by hiring away" has contributed to the diffusion of knowledge from the traditional R&D departments of large integrated firms to an ever increasing number of specialized start-ups. By contrast, socially distributed knowledge—which is inextricably embedded in organization structure, and which can only be mobilized in the firm-specific context of carrying out a multi-person productive task—has seemingly greater governance ramifications. On the basis of the above observations, we suggest that future research should probably try to differentiate personal tacit knowledge from collective tacit knowledge, and to differentiate tacit knowledge of craftsmanship from tacit knowledge of a cognitive type.

7.2 Limitations of this study

7.2.1 Survey data

In this research, project- and firm-level data regarding (1) the organizational choices of R&D projects; (2) the contextual characteristics of the R&D projects (e.g., problem attributes, knowledge characteristics, transactional attributes etc.), and; (3) other relevant control variables are collected by survey (questionnaire). Since most of the explanatory variables in this research are often hard to measure and are typically not available from open source, the use of survey enables us to gather information on variables of interest and to construct a dataset that fits our research need. At the same time, some of these data are subject to the well-known general limitations of survey data—namely, that they are often based on the respondents' stated beliefs, rather than on their beliefs or judgements revealed through choice, which gives rise to inaccurate measurement. To avoid this problem, particular attention has been paid to the wording of the questionnaire questions to make it as understandable as possible, often with reference to questionnaires of similar nature used in previous studies. Relatedly, since these measurements are based on ordinal rankings, it is hard to compare them consistently across industries (or even across different persons from the same firm). For example, what is rated as a relatively specialized asset in one industry may be rated quite differently in another industry, and what a firm in a specific industry considers a comparatively uncertain circumstance may be the standard operating environment in another industry (Shelanski & Klein, 1996). Accordingly, we intentionally avoid a multi-industry study to avoid inconsistent measurement across industries.

7.2.2 Reduced form regression, multiple interpretations, performance implications and the assumption of efficient selection process

In this research, we adopt reduced-form regression models to estimate the linkages between observed organization choices and the few critical contextual variables identified by various streams of the thought.

As Masten et al. (1991) pointed out, reduced form estimations bring interpretative problems as the structural coefficients in a reduced-form regression can be identified only up to a proportionality factor[2]; tests regarding organizational choice are thus based on the signs and relative magnitudes of the structural coefficients and such "indirect tests are unable to distinguish whether observed patterns of organization resulted from systematic, but as yet unexplored, variations in the costs" (Masten et al., 1991: p. 17) incurred in organizing the productive activities. As a general rule, for any empirical research that employs a reduced form analysis, the data could potentially be consistent with more than one theoretical explanation. For example, in the case of TCE empirical research, the absence of direct measures of transaction costs, together with the inherent drawback of reduced-form estimations, have in many cases left ample room for a non-transaction cost explanation to be viable (Masten, 1996).

Relatedly, Masten also noted that for the part of studies based on the reduced form regression technique, "whether a theory of governance choice is a good predictor of actual behavior reveals little about the cost of failing to choose the correct organization arrangement and may be a poor guide to whether a particular theory offers sound prescriptions for business decisions" (Masten, 1993: p. 199). Performance implications of organizational choices drawn from such analysis are not totally convincing because they are conditioned on the assumption than an efficient selection process for competing organizational modes is working in the background.

[2] See section 6.3.1 in chapter 6 (A Note on the Probit Model).

To be more exact, empirical research based on the reduced-form analysis implicitly assumes that market forces work "in a general, background way on the efficacy of competition to perform a sort between more and less efficient modes and to shift resources in favor of the former" (Williamson, 1985 p. 22). In other words, inefficient governance arrangements will tend to be discovered and undone. Only if this assumption is valid, can we draw inference regarding the performance implications of organizational choices from what we actually observe (Masten, 1993). Obviously, this is a strong assumption and its plausibility can not always be justified. For example, when a new organization option turns up for the first time, the managers, being bounded rational economic agents, might not have correct perceptions of the costs and benefits of such new organization option. In this case, the firm may make mistakes with regards to their organizational choices and it takes time for the market to correct such mistakes. Without controlling the selection process at stake, empirical researchers are not totally confident of how much organization choices matter for performance (Yvrande-Billon & Saussier, 2004). In our research, we confine the sectoral coverage of our data collection to the consumer electronics industry partly because this industry is generally regarded as being in the mature stage, where the assumption of efficient selection process may be more or less satisfied.

More recently, some new econometric techniques (Hamilton & Nickerson, 2003; K. J. Mayer & Nickerson, 2005; Nickerson & Silverman, 2003; Poppo & Zenger, 1998; Sampson, 2004a; Shaver, 1998) have been applied to address the problem. To be more exact, apart from using the reduced form regression to estimate the relationship between organization choices and contextual characteristics[3], they go further to investigate whether deviation from predicted choice leads to poorer performance. In doing so, special attention has been paid to correct for self-selection bias and endogeneity between performance and organizational choices (Hamilton & Nickerson, 2003; K. J. Mayer, 2009; Yvrande-Billon & Saussier, 2004). Simply put, these problems result from omitted variables that affect both the organizational choice and the performance (Hamilton & Nickerson, 2003). Unbiased estimation requires econometric methods that account for omitted variables. Such methods statistically correct for decision makers' self-selection of a particular organizational choice—that is, whether an observation is in a subset of the sample (organized under one specific mode) rather than another is not random, it depends in part on some factors that also affect performance (Poppo & Zenger, 1998).

[3] These new empirical techniques use a two-stage regression procedure. What has been done in the first stage is roughly the same as that in the traditional model.

In this research, we do not include performance as the dependent variable (to be more exact, we do not collect data on performance in our survey), thus we are unable to examine the performance implications of alignment and misalignment.

7.2.3 Endogeneity

As just noted, if we want to examine the performance implications of organizational choices, endogeneity and selection bias require special attention. In fact, even for studies that adopt the traditional reduced form analysis, endogeneity is a very general problem. For example, Macher and Richman (2008) note that an important gap in the existing empirical TCE literature concerns the endogeneity of transaction cost variables, most notably asset specificity. To be more exact, in this literature, it is often assumed that the level of asset specificity is independent from the decision to choose a given governance structure. However, as noted by Riordan and Williamson (1985), it is possible that the level of asset specificity is also a choice made by the firm and such a decision might not be independent of the firm's governance choice. In this case, asset specificity should be treated as endogenous. Failure to address the problem could result in significant estimation biases (Masten et al., 1991), but only a handful of studies have made efforts in this regard (Lyons, 1995; Nickerson, Hamilton, & Wada, 2001; Saussier, 2000).

Our research does not attempt to correct for endogeneity between explanatory variables and organizational choice. Naturally, our estimation results might be biased.

7.2.4 Small Sample Size

Given the nature and costs of the data, we only manage to collect a total of 142 valid observations by questionnaires. On the basis of this dataset, we use binomial and multinomial regression techniques to examine the determinants of organizational choice and then test some hypotheses regarding the relationship between certain variables of interest. Given the size of our sample, the general limitations (S. F. Slater & Atuahene-Gima, 2004) to studies based on small sample size apply. In particular, the following point might be worth noting.

The ability of a statistical test to correctly reject a null hypothesis (i.e., the power of a statistical test) depends largely on (1) the sample size and; (2) the strength of the relationship between the variables of interest (Sawyer & Ball, 1981; Sawyer & Peter, 1983). Large samples allow even very small effects to be statistically significant.

It has been reported (Phelan, Ferreira, & Salvador, 2002) that the average sample size for studies published in the Strategic Management Journal was 175. This suggests, studies based on small sample size are not unusual in this field, and there should be no bias against statistically significant results derived from small samples if the samples are representative enough of the whole population (Sawyer & Peter, 1983).

Due to the generally weaker relationships found in multi-industry studies, to reject properly the null hypothesis in such studies, a larger sample if often required. Conversely, due to the more homogeneous nature of the relationship within the same industry, and the study's control for inter-industry differences and market-level effects, single-industry studies may be conducted with smaller samples, as long as the researcher is satisfied with being able to detect only reasonably substantial effects (S. F. Slater & Atuahene-Gima, 2004). By its nature, our study is basically a single-industry study in which the sectoral coverage of the data collection is confined to the consumer electronics industry.

It has been noted in previous studies of similar nature that in a questionnaire survey, to avoid too small a sample size, a respondent is often encouraged to report multiple cases which might result in serial correlation between the many observations reported by the same person. In this study, we take measures to deal with the problem. On average, each respondent reported information on 1.28 projects, and each participating company contributed 2.84 observations; thus the potential serial correlation problem would not be a serious concern.

In this study, we use both binomial and multinomial regression techniques. In the binomial estimations, the organizational choices are treated as a series of binary choices and in each of the binomial probit models, only a subset of the data is used. In the multinomial estimations, the dependent variable is treated as a variable with three or four alternatives. Given the practical constraints of *small sample size*, we have to focus on explanatory variables that are most relevant (as suggested by previous studies) and that are of greatest interest to us. This means, we are unable to include more control variables which in general tends to reduce the overall fit of the models.

Finally, being a single-industry study, we are aware that results derived from this study, regardless of the internal validity or the size of the effects, must be repeated in more settings before any general conclusion about the validity of the theory being tested can be made.

7.3 Key Contributions of the thesis: Some Concluding Remarks

The thesis is mainly intended to contribute to the problem-solving approach to the boundary determination of the firm, both theoretically and empirically.

On the theoretical side, we provide a detailed review of the existing problem solving perspective literature (Chapter 4), with the aim to present its basic insights, to demonstrate its substantial potential, to identify the gaps in the existing research and to sketch out some directions for further developing this perspective.

In short, the problem-solving approach to the boundary determination of the firm seeks explicitly to combine transaction cost economics (Williamson, 1975, 1985b, 1996b), complexity theory (Simon, 1962; Kauffman, 1995) and the knowledge-based view of the firm (Conner, 1991; Conner & Prahalad, 1996; Demsetz, 1988; N. J. Foss, 1996a, 1996b; Kogut & Zander, 1992, 1993, 1996) in explaining how different organizational forms govern the efficient creation of valuable knowledge.

In many aspects, the problem-solving perspective follows the method of "discrete structural analysis" developed by Williamson (1991). Although it adopts a different unit of analysis from TCE, the problem solving perspective applies similarly the logic of "discriminating alignment" (Williamson, 1991) in evaluating the relative costs and competencies of alternative governance mechanisms in solving problems with different attributes.

Specifically, based on Simon's work on problem solving (1962, 1973), Kauffman's (1993) work on the NK modelling, and Kogut and Zander's contributions to the knowledge-based view of the firm (1988; 1992, 1993, 1995), a few problem attributes (i.e., problem complexity, decomposability, and problem structure) and knowledge characteristics (i.e., knowledge tacitness and social distribution) are identified as being crucial in understanding the impediments to problem-solving activities (knowledge-transfer and knowledge-formation hazards) (Brusoni et al., 2007; Heiman & Nickerson, 2002, 2004; Macher, 2006; Nickerson & Zenger, 2004). On this basis, it is also suggested that different search methods (heuristic or local trial-and-error) and different problem types can be matched in a way that realizes superior search performance (Gavetti, 2005; Gavetti & Levinthal, 2000; Sommer & Loch, 2004; Winter et al., 2007). Furthermore, it is contended that as far as the costs and competencies for implementing solution searches for different types of problem are concerned (by mitigating knowledge formation hazards and other impediments), the few generic organizational modes differ with respect to the dimensions of incentive intensity, communication channels, and dispute resolution regime (Heiman

& Nickerson, 2002, 2004; Leiblein et al., 2009; Nickerson & Zenger, 2004). Finally, the problem-solving perspective works out the match between these problem/knowledge attributes and the few generic organization modes—markets, hierarchies, and alliances—in an economizing manner that enables efficient solution search and maximizes expected values of problem solving (Heiman & Nickerson, 2002; Leiblein & Macher, 2009; Macher, 2006; Nickerson & Zenger, 2004).

We contribute to the problem solving literature in the following ways.

Firstly, we review systematically the NK modelling literature and link it more closely with the problem solving perspective. Although it is generally acknowledged that the NK modelling literature is a source of theoretical inspiration to the problem solving perspective, this literature is probably less familiar to most economists working with the theory of the firm. What are the basic insights of this literature? How could these insights be linked to the problem solving perspective? These topics are less reviewed systematically in the problem solving perspective literature. We fill this gap by introducing the basic elements and methods of the NK simulation, highlighting its advantages and shortcomings, and presenting the basic insights of some recent economic and strategy applications of NK modelling. Specifically, the formal structure of the NK models allows one to clearly define complexity and to precisely delineate adaptation mechanisms, which helps not only to clarify the association between particular strategies (adaptive principles or search methods) and performance (fitness) in more or less complex environments (fitness landscape), but also to observe intuitively the underlying process (Ganco & Hoetker, 2009). Moreover, in these applications, certain elements of organizational form have been linked to some specific search mechanisms which exhibit different search efficiency for different problems. Overall, the insights of the stream of literature that links organization forms, search mechanisms and problem complexities seem to suggest: the desired structure of the organization should try to mirror the "true" structure of the underlying problem or decisions (in terms of the nature of interdependencies between its elements, hierarchical and/or decomposable), so as to stimulate the development of desired interdependencies and to facilitate the adaptation and problem-solving. That being said, in this literature, it is still not entirely clear whether and how different organizational forms differ in their costs and competencies in implementing different types of search.

The second theoretical contribution of this thesis is the identification of some non-trivial gaps in the theory of the problem solving perspective. We then sketch out some specific ways for fixing the problems and for further developing the problem solving perspective.

Specifically, on the basis of an extensive review of the problem-solving literature, (1) we argue that knowledge-set interaction and decomposability are two analytically distinguishable dimensions. Accordingly, they should be treated as two separate variables; (2) with reference to some other closely related literature such as the knowledge-base view, organizational learning, innovation, etc, we contend that a firm's existing knowledge has profound impacts on the organization and performance of its problem solving activities; however, this dimension has been missing or at least has been seriously ignored in the existing problem solving literature; (3) we note that the problem solving perspective has mainly been applied to the choice of "make" or "buy", but less to other organizational choices (e.g., the choice among various alliance forms, or the choice between in-house and alliance), and we doubt, as far as the costs and competencies of governing different types of problem-solving are concerned, whether alliances are really "hybrid" modes of organization lying somewhere between the polar modes of arm's length market contract and hierarchy along a hypothetical continuum; (4) we note that the problem solving perspective has mainly been applied to the organization of R&D activities (technological problem solving), we contend that once joined with Porter's activity-based analysis (in particular, the value chain analysis), the PSP framework can be applied to other non-R&D activities and be further developed into a more general theory of economic organization. We sketch out some specific ways of doing so.

On the empirical side, we contribute to the problem solving perspective in the following two aspects.

In the first place, we offer a very detailed review of empirical evidence relevant to the problem-solving perspective (Chapter 5).

Admittedly, as an emerging perspective, very few empirical studies are expressly designed to examine the problem-solving perspective. This does not mean, however, that relevant empirical evidence exists only in the empirical PSP literature. In fact, in some other streams of literature which are closely related to the problem solving perspective (in particular, the knowledge-based view literature and the transaction cost economics literature), many of the relevant variables have been explored in some way. Accordingly, our review extends into these background literatures. For each variable, the organizational ramifications for the make-or-buy decision and for alliance governance will be discussed separately.

In our review, variables are grouped into three categories: (1) those related to problem complexity—i.e., problem structure, complexity, and decomposability; (2) those related to a firm's existing knowledge base—i.e., absolute and relative knowledge base, breadth and depth of knowledge base; and (3) those related to knowledge characteristics—i.e., tacitness and social distribution/embeddedness of knowledge.

As far as the make-or-buy choice is concerned, the limited empirical evidence relevant to the first category of variables (mostly derived from studies that were expressly designed to test the problem solving perspective) are rather supportive of the predictions of the problem solving perspective—i.e., the more complex, and the more ill-structured a technological problem is, the more likely that the problem solving will be organized internally. When the choice is between various forms of alliance, it is found that the more ill-structured and the more complex an inter-firm collaboration is, the more likely that an equity-based alliance will be chosen to govern this collaboration. Moreover, it has also been found that, in the face of complexity, the adoption of equity-based governance is mainly motivated by concerns over coordination issues rather than incentives alignment. To put it somewhat differently, the empirical evidence indicates that the major challenge of greater complexity for the governance of collaboration is mainly about coordination, not incentive alignment. Obviously, this is supportive of the prediction of the problem-solving perspective rather than transaction cost economics.

Empirical evidence regarding the boundary implications of complexity can also be found in the empirical TCE literature. Generally speaking, relevant empirical evidence in this literature leans toward a positive association between complexity and vertical integration. However, in this literature, there is considerable ambiguity concerning the meaning of "complexity", and there is also a considerable diversity in its operational measures. Hence, in most cases, the same result is liable to multiple interpretations. Given this, relevant empirical evidence in the TCE literature is less conclusive.

As noted in Chapter 4, in the problem solving literature, the organizational implication of a firm's existing knowledge base is largely ignored. By contrast, in the knowledge-based literature, the theme has been explored to some extent, although not necessarily in the context of a firm's problem solving (technological development) activities. Generally speaking, when the choice is between "make" or "buy", the empirical evidence in the knowledge-based view literature tends to support a positive association between a firm's existing knowledge-base and the choice of internal organization (i.e., the higher the firm's existing knowledge base is, the more likely that a productive activity will be organized in-house).

In the context of alliances, existing empirical literature tends to focus on the relationship between a firm's existing knowledge base and its propensity for alliance participation. Although current theoretical insights lean towards a positive association (i.e., firms with a higher level of absolute knowledge-base have a higher propensity for alliance participation than those with a lower level of absolute knowledge-base), the empirical evidence is less than conclusive.

More recent studies indicate that the inconclusiveness of the findings can be attributed, in part, to the diversity of the measures that have been used to capture the firm's absolute magnitude of knowledge base. In this context, the breadth and the depth of a firm's knowledge base are further differentiated, and it is argued that a broader knowledge base adds to the possibility of coming into alliances, whereas a deeper knowledge base works to the contrary. Both of the hypotheses are then tested empirically, and the results are broadly corroborative.

Empirical evidence relevant to the third category of variables is probably the most underdeveloped. Overall, the stream of empirical literature is more concerned with the competitive/innovative implications rather than the boundary implications of tacit and socially distributed knowledge. For those studies that explore the governance implications of tacit and socially distribute knowledge, a majority of studies investigate the relationship between knowledge tacitness and relational governance, whereas its ramifications for formal governance are less explored. That being said, a limited number of empirical studies explore the implications of knowledge tacitness for the choice of alliance governance, and the results of these studies tend to confirm Kogut's (1988a) "received wisdom" that equity-based alliances are more effective vehicles than contract-based alliances for the transfer of tacit knowledge between partners. An even smaller number of studies investigated the boundary implications of socially embedded knowledge, and the very limited empirical evidence provides some preliminary support for the argument that knowledge dispersion is positively associated with both the adoption of certain more costly knowledge management practices (e.g., high-bandwidth communication channels) and the choice of equity-based governance form.

A second aspect of our contributions consists of an empirical examination of the problem solving perspective (Chapter 6).

Using data collected from the Chinese consumer electronics industry, we empirically examine the underlying determinants of the firms' organizational choice for their R&D activities, which, in the first place, is deemed as a problem solving process given their existing knowledge base. Special attention is therefore devoted to those variables associated with the problem-solving approach in the KBV.

In Chapter 6, we start by outlining the method and process of our data collection, as well as the industrial background of our empirical setting. We then explain how the dependent and independent (explanatory) variables in our analyses are defined and measured. Econometric analyses using binomial and multinomial regression techniques comprise the main part of this chapter. In the stage of binary analysis, the organizational choices are treated as a series of binary choices and the probit regression technique is used to identify the determinants of these choices. Specifically, the section begins with a discussion of some of the technical details of the binary probit model. The estimation results of a series of binary probit models are then presented and the underlying determinants in each circumstance are separately identified. In the stage of multinomial analysis, we start by introducing at some length the technical details of the multinomial logit model. On the basis of these technical discussions and using the first-stage results as a benchmark, we present the results of the multinomial logit estimation..

On the basis of the empirical analysis and the review of the existing empirical literature, we compare our results with those of the relevant existing literature and make some comments (section 1 of this chapter). The following points are worth repeating.

In general, the few problem-solving perspective and knowledge-based view variables are far better predictors of a firm's organizational choices than the few transaction costs economics variables. In other words, our results lend more support to the problem-solving perspective and the knowledge-based view, rather than the transaction cost economics.

Our results indicate that a firm's existing knowledge base is the most significant variable in explaining a firm's organizational choice of technological problem solving; while in the existing problem solving literature, the role of a firm's existing knowledge base has largely been ignored.

Our results also suggest that the effects of problem complexity (knowledge-set interaction) and decomposability do not always pull in the same direction, which lends support to our argument that complexity and decomposability should be treated as two distinct variables.

Contrary to the general prediction of the existing problem solving perspective literature, our results reveal that as far as the choice between in-house and alliance is concerned, a higher level of complexity tends to favour the choice of alliance rather than in-house, suggesting that alliance is more efficient for solving more complex problems. This also means, as far as the costs and competencies of governing different types of problem-solving are concerned, alliances are probably not "hybrid" modes of organization. Rather, they are distinct types of organizational in their own right.

Finally, at odds with most of the existing studies that investigate the governance implications of knowledge tacitness, our results suggest that knowledge tacitness is not significant for any of the organizational choices. By contrast, ***social distribution (embeddedness) of knowledge*** is estimated to be a significant determinant for some of the organizational choices.

Apart from the above key contributions, we also offer two detailed reviews of the background transaction cost economics literature. Specifically, Chapter 2 reviews the evolution of the concept of transaction costs in transaction cost literature, aiming to highlight the basic logic of the transaction cost economics as well as the diversity of the literature, and to demonstrate how the concept is applied to the boundary determination of the firm. Chapter 3 reviews Oliver Williamson's theory of the firm, aiming to illustrate the basics of his method, to highlight his major contributions, and to identify the strengths and weaknesses of his theory.

Given that the transaction cost economics is the dominant approach (in particular, Williamson's approach) in this field, and that in many aspects, the problem-solving perspective follows the method of "discrete structural analysis" developed by Williamson, these two reviews are highly relevant to our discussion.

Appendix I: The Questionnaire

Q 1

Please fill in your name, title, email address, and telephone number (in case we need to contact you):

Respondent's name: ___________________________

Respondent's title: ___________________________

Company address: ___________________________

Telephone number: ___________________________

Contact Email: ___________________________

Q 2 (Firm Size)

How many employees work in your company? _______________

Average Sales Revenues of yours company in the past 3 years?
_______________US$

Q 3 (Nature of Ownership)

In terms of ownerships, what is the nature of your company? (Please tick the appropriate item)

○ A Sino-foreign joint venture

○ A wholly-owned subsidiary of a foreign company

○ A Chinese company

Is your company independent or are you a subsidiary of another company? _______________

If you are a subsidiary of another company, please state the name of your parental company (if you are a joint venture, please state the names of all of your parental companies) _______________

Q 4

The focus of this questionnaire is the ***organizational modes*** of R&D projects which involve ***an international element***.

The terms "***an international element***" refer to one of the following cases:

- A R&D project undertaken in mainland China by a joint-venture or a wholly-own subsidiary of foreign company (either production or R&D oriented) ***in which the equity structure acts as an essential umbrella to support the R&D project under consideration***.
- A collaborative R&D project undertaken in mainland China jointly by a Chinese company and its foreign partner(s).
- A R&D project undertaken by a Chinese company in a foreign country (either independently or in collaboration with a foreign partner)
- A R&D project contracted out (outsourced) to a Chinese company by a foreign company or a joint-venture.
- A Chinese company acquiring a technology license from a foreign licensor to support a R&D project (e.g., as an essential input for that R&D project).

The ***organizational modes*** of R&D projects are often classified into three broad categories, i.e.: In-house, collaborative arrangements and outsourcing (i.e., arm's-length like contract)

In-house means to undertake the R&D project within the firm.

Outsourcing means to contract out a R&D project to some other organization to look for a technological solution; or to purchase a ready-to-use solution that could be easily integrated into the company's existing system with little or no adaptation. It should be emphasized that when a R&D project is organized by outsourcing, it is essentially a cash for technology exchange that approximates arm's-length contract, in which the flow of knowledge is unilateral, often in highly codified or symbolized forms such as blueprint, recipes, or components embodying the solution. In particular, a unilateral technological license, by which the licensee acquires a ready-to-use solution for a specific problem, is classified as a form of outsourcing.

Collaborative arrangements (also known as "alliance") refer to a wide variety of hybrid organization modes lying somewhere between in-house organization and pure arm's-length transaction. Distinction has been made between ***contract-based collaborative arrangements*** and ***equity-based collaborative arrangements***.

In the former category (***contract-based collaborative arrangements***), partner firms, by setting up a mutually agreed on contract, combine their respective resources (in particular, technological expertise) in a collaborative R&D project, and the contract does not involve equity arrangement. Under a contract-based collaborative arrangement, partner firms work hand-in-hand, and there are active knowledge exchanges between each other.

A second category of collaborative arrangements is ***equity-based collaborative arrangements***. Under such arrangements, partner firms adopt the holding of equity as an umbrella to support their joint R&D project(s). They might either jointly invest and set up a joint venture (be it a manufacturing joint-venture or a R&D joint-venture), and then jointly own and operate the new legal entity in which multiple R&D projects are undertaken; Alternatively, to support a joint R&D project, the partner firms might take minor equity positions in each other without setting up a separate legal entity for their collaboration.

Summing up, for the purpose of this questionnaire, the organizational modes of R&D are classified in the following way.

Organizational Mode	**In-house**	**Collaborative Arrangements**		**Outsourcing (Arm's-length Like Contract)**
		Equity-based Collaborative Arrangement	**Contract-based Collaborative Arrangement**	
Examples	Wholly-owned subsidiary (either manufacturing , marketing, or R&D oriented)	production Joint venture (in which joint R&D projects are undertaken); R&D joint venture	Co-development contract; Bilateral licensing	Unilateral licensing; R&D outsourcing contract; OEM; ODM

Using this classification and the definitions given above, could you please give us a few examples of R&D projects undertaken by your company (either independently or in collaboration with other organization) which involves an international element. In terms of their organizational modes, it is preferable that the R&D projects you are reporting are as diversified as possible.

	In-house	**Equity-based collaborative arrangement**	**Contract-based collaborative arrangement**	**Outsourcing**
Project 1	○	○	○	○
Project 2	○	○	○	○
Project 3	○	○	○	○

The questions that follow are about the circumstances surrounding the R&D projects you are reporting. The answers to the questions are presented as a five-scale choice. Please tick the one you deem appropriate. Sometimes a brief definition is provided to clarify the meaning of some specialized terms

Q 5 (Complexity)

As a rough approximation, any R&D project could be deemed as the search for a solution to a technological problem. Once the problem is successfully solved, new knowledge is created. To a large extent, such new knowledge is some unique combinations of existing knowledge.

Please read the following background definitions carefully, and then use these definitions to tick the answer you deem appropriate.

Definition: well-structured problem/ill-structured problem

*We define a **well-structured problem** as one with a clear boundary of the relevant knowledge sets, and; a thorough understanding of the interactions between these relevant knowledge sets, and; consequently, there are explicit and widely-accepted approaches for solving the problem.*

*Conversely, for an **ill-structured problem**, the boundary of the relevant knowledge sets is ambiguous, and; the understanding of the interaction between the relevant knowledge set is poor/incomplete, and sometimes these interactions are unknown or unexpected; consequently, no consensus approach exists for solving the problem.*

As far as the R&D project is concerned, is the problem you are trying to solve a well-structured problem or an ill-structured problem?

	Highly well-structured	Fairly well-structured	Right in the middle of the two extremes	Fairly ill-structured	Highly ill-structured
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Definition: complex/simple problem

We define the complexity of a problem in the following manner:

*A **simple** problem involves very few relevant knowledge sets, and the degree of interactions/interdependencies between these knowledge sets is low.*

*Conversely, a **complex** problem involves a large number of relevant knowledge sets, and the degree of interactions/interdependencies between these knowledge sets is high.*

As far as the R&D project is concerned, how complex is the problem you are trying to solve?

	Very simple	Fairly Simple	Neither complex nor simple	Moderately complex	Highly Complex
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Definition: decomposable / non-decomposable problem

We define the decomposability of a problem in the following manner:

*A **decomposable** problem is one that can be subdivided into sub-problems; each of the sub-problems draws from rather specialized knowledge sets and could therefore be solved quite independently.*

*Conversely, a **non-decomposable** problem cannot be subdivided, as the knowledge sets interactions within the problem are so extensive that it is virtually impractical to define sub-problems. For such problem, if a solution is to be found, it has to be an overall solution.*

As far as the R&D project is concerned, to what extent is the problem you are trying solve can be subdivided into sub-problems which could be solved relatively independently?

	Perfectly sub-divisible	**Easily sub-divisible**	**Right in the middle of the two extremes**	**Not easily sub-divisible**	**Not sub-divisible at all**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Q 6 (Existing Knowledge Base)

As far as the structure of the problem is known, to what extent does your company possess the relevant knowledge that is required to solve the problem when the R&D project is initiated?

	Almost none of the required knowledge	**A small proportion of the required knowledge**	**Half of the required knowledge**	**A majority of the required knowledge**	**Almost all the required knowledge**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Q 7 (Demand Uncertainty)

In general, the results of a R&D project contribute to the variety/quality/cost reduction of the product(s)/service(s) a company could offer. At the time *when the R&D project was initiated*, how difficult it was to forecast the future demand of product(s)/service(s) to which the R&D project was intended to contribute?

	Very easy to forecast	**Fairly easy to forecast**	**Right in the middle of the two extremes**	**Fairly difficult to forecast**	**Almost impossible to forecast**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Q 8 (Human Asset Specificity)

Assume that the R&D project fails to achieve its objective, to what extent the experience/knowledge gained/developed during this project is still useful outside this project?

	Very useful	**Somewhat useful**	**Not very useful**	**Almost useless**	**Totally useless**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Q 9 (Physical Asset Specificity)

To support a R&D project, the firm might invest in physical assets, e.g., research facilities and instruments. Assume that the R&D project fails to achieve its objective, to what extents the physical assets invested to support the project are still useful outside this project?

	Very useful	**Somewhat useful**	**Not very useful**	**Almost useless**	**Totally useless**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Q10 (Appropriability)

To what extent the result of the R&D project in question can be easily imitated by an outsider (say, by reverse engineering or inventing around) in a timely fashion?

	It is almost impossible that the result be imitated	**It is fairly difficult that the result be imitated**	**To imitated the result is neither easy, nor difficult**	**It is fairly easy that the result be imitated**	**It is very easy that the result be imitated**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

In case one or few of the R&D team members leave your company and work for your competitor, will the event lead to substantial leakage of the valuable results/knowledge to your competitor?

	No, that is impossible	**No, that is unlikely**	**Yes, that is somewhat possible**	**Yes, that is quite likely**	**Yes, that is definitely**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Q 11 (Tacitness of Knowledge)

In general, a formal and symbolic language cannot always explain/convey all the knowledge, techniques, methods and experience. Some of the knowledge is implicit and such implicit knowledge is learned mainly through examples, trainings, experiences and practices.

As far as the structure of the problem is known (i.e., the boundary of the relevant knowledge sets and their interactions), is it the case that you can easily find some relevant reference books/blueprint/manuals (to be more general, materials in printed or electronic form) that could deliver the critical knowledge in an accessible way to a new team member who is of average competence and with adequate training in relevant fields? Or if such materials are not readily available, is it quite easy to produce them—say, for the purpose of internal training—if such a practice turns out to be absolutely necessary?

	Yes, that is exactly the case	**Yes, that is mostly the case**	**In our case, I can neither agree nor disagree with you**	**No, the case is roughly to the contrary**	**No, the case is absolutely to the contrary**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Some knowledge is communicable/teachable, some isn't. When relevant knowledge is highly communicable/teachable, it exhibits the following characteristics:

New team members with adequate training in relevant fields can easily learn relevant knowledge and skills on how to perform their jobs by talking to and working with skilled team members.

Training new team members is a quick, easy job.

New team members know enough after vocational training on how to perform their jobs.

Based on these characteristics, to what extent do you think the knowledge required to undertake the R&D project is communicable/teachable?

	It is highly communicable / teachable	**It is mostly communicable / teachable**	**It is neither easy, nor difficult to communicate/ teach relevant knowledge**	**It is very difficult to communicate/ teach relevant knowledge**	**It is almost impossible to communicate/ teach relevant knowledge**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Q 12 (personal/socially distributed knowledge)

As far as the R& D project is concerned, is it possible that one individual expert could have all the relevant critical knowledge required to solve the targeted problem? Or, on the other hand, these critical knowledge are widely distributed among different individuals in the teams such that is it almost impossible for a single expert, no matter how erudite he/she might be, to possess all the relevant critical knowledge required to solve the problem?

	I could think of a few experts who possess all the relevant knowledge	**It is quite likely that a single expert could possess all the relevant knowledge**	**It is not inconceivable that a single expert could possess all the relevant knowledge**	**It is unlikely that a single expert could possess all the relevant knowledge**	**It is not possible at all that a single expert could possess all the relevant knowledge**
Project 1	○	○	○	○	○
Project 2	○	○	○	○	○
Project 3	○	○	○	○	○

Appendix II

Table A-6-1: Logit Estimation Results (In-house vs. Outsourcing)

Logit regression	Number of obs = 84
Number of cases 'correctly predicted' = 76 (90.5%)	LR chi2(12) = 65.77
Log likelihood = -16.422	Prob > chi2 = 0.0000
Adjusted R2=0.403	Pseudo R2 = 0.667

	Predicted Sign	*Coefficient (Std. Error)*	*z*	*p-value*	
const		-26.949 (9.573)	-2.815	0.005	***
PS	+	0.345 (1.064)	0.325	0.746	
COM	+	1.076 (1.031)	1.043	0.297	
DEC	+	2.756 (1.600)	1.722	0.085	*
EKB	+	4.247 (1.466)	2.897	0.004	***
COD	+	-0.422 (0.891)	-0.474	0.636	
TEA	+	1.017 (1.110)	0.917	0.359	
SDK	+	-0.175 (0.445)	-0.393	0.694	
DU	+	-0.449 (0.699)	-0.642	0.521	
HAS	+	-0.523 (0.913)	-0.573	0.567	
PAS	+	1.669 (0.999)	1.671	0.095	*
AP1	+	-1.031 (0.765)	-1.349	0.177	
AP2	+	1.332 (0.831)	1.602	0.109	

*** p<0.01; ** p<0.05; * p<0.1

Table A-6-2: Classification Table (Model 2A)

		Predicted		*Percentage Correct*
		0	1	
Actual	0	18	5	78.3
	1	3	58	95.1
Overall Percentage				90.5

Table A-6-3: Model 5B: Multinomial Logit Estimation Results (Four Alternatives)

Multinomial logistic regression
Number of cases 'correctly predicted' = 88 (62%)

Log likelihood = -125.52

Number of obs = 142
LR chi2(24) = 118.31
Prob > chi2 = 0.0000
Pseudo R^2 = 0.3203

	Predicted Sign for Coef.	*Coef. (Std. Err.)*	*RRR (Std. Err.)*	*z*	*p-value*		*Predicted Sign for Coef.*	*Coef. (Std. Err.)*	*RRR (Std. Err.)*	*z*	*p-value*		*Predicted Sign for Coef.*	*Coef. (Std. Err.)*	*RRR (Std. Err.)*	*z*	*p-value*	
const		4.067 (3.527)		1.15	0.249			13.918 (3.572)		3.90	0.000	***		20.684 (4.311)		4.80	0.000	***
PS	-(?)	-0.133 (0.473)	0.876 (0.414)	- 0.28	0.779		-(?)	0.068 (0.455)	1.071 (0.487)	0.15	0.880		-	-0.934 (0.602)	0.393 (0.237)	- 1.55	0.121	
COM	+(?)	1.172 (0.535)	3.228 (1.726)	2.19	0.028	**	+(?)	0.787 (0.494)	2.197 (1.085)	1.59	0.111		-	-1.086 (0.727)	0.338 (0.245)	- 1.49	0.135	
DEC	-	-1.631 (0.648)	0.196 (0.127)	- 2.52	0.012	**	-	-1.067 (0.606)	0.344 (0.209)	- 1.70	0.078	*	-	-0.534 (0.812)	0.586 (0.476)	- 0.66	0.511	
EKB	-	-1.635 (0.490)	0.195 (0.096)	- 3.34	0.001	***	-	-2.188 (0.489)	0.112 (0.055)	- 4.40	0.000	***	-	-2.774 (0.572)	0.062 (0.036)	- 4.85	0.000	***
SDK	-	-0.081 (0.278)	0.922 (0.256)	- 0.29	0.770		-	-0.707 (0.282)	0.493 (0.139)	- 2.51	0.012	**	-	0.215 (0.388)	1.240 (0.481)	0.55	0.580	
HAS	-	-0.678 (0.453)	0.507 (0.230)	- 1.50	0.134		-	-0.393 (0.471)	0.675 (0.318)	- 0.80	0.404		-	0.133 (0.688)	1.143 (0.786)	0.19	0.846	
PAS	-	0.113 (0.418)	1.120 (0.468)	0.27	0.787		-	-0.396 (0.408)	0.673 (0.274)	- 0.90	0.331		-	-1.381 (0.644)	0.251 (0.162)	- 2.15	0.032	**
AP2	-	0.755 (0.456)	2.129 (0.970)	1.66	0.097	*	-	-1.075 (0.446)	0.341 (0.152)	- 2.40	0.016	**	-	-1.051 (0.607)	0.349 (0.212)	- 1.73	0.083	*

*** $p<0.01$; ** $p<0.05$; * $p<0.1$

Table A-6-4: Classification Table (Model 5A)

		Predicted				*Percentage Correct*
		1	2	3	4	
Actual	1	51	1	5	4	83.6%
	2	8	3	7	6	12.5%
	3	11	1	16	6	47.1%
	4	3	1	1	18	78.3%
Overall Percentage						62.0%

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