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Evaluating the Economy-Wide Impact of Demand and Supply Disturbances in the UK: A Computable General Equilibrium Analysis of Current Regional and National Policy Concerns

by

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TABLE OF CONTENTS

LIST OF APPENDICES

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

LIST OF TABLES

CHAPTER 3

CHAPTER 4

CHAPTER 6

APPENDIX A

APPENDIX B

APPENDIX F

APPENDIX H

LIST OF FIGURES

CHAPTER 2

CHAPTER 6

APPENDIX A

APPENDIX D

APPENDIX E

APPENDIX G

APPENDIX H

ABSTRACT

Evaluating the Economy-Wide Impact of Demand and Supply Disturbances in the UK: A Computable General Equilibrium Analysis Relating to Current Regional and National Policy Concerns

In this thesis I evaluate the economy-wide impacts of a number of distinct, but related, policy-induced regional or national shocks using a Computable General Equilibrium (CGE) framework of the UK regional and national economies. One particular aim of the research is to address a specific shortcoming in current UK government policy evaluation: the absence of a full spatial impact assessment of devolved and regional policies. In recent years, the UK Labour government has advocated the use of spatially differentiated and devolved regional policy as a means of increasing prosperity. Despite this, there exist no government guidelines relating to the treatment or measurement of interregional spillover effects associated with such policies. Furthermore, relatively few UK regional policy studies consider the effects of the policy on non-target, or national economies.

I address this issue by conducting a more comprehensive evaluation of regional policy effects. This involves a number of aspects. Firstly, I identify the full spatial impact of the policy by estimating both the regional and national effects of a policy change. Secondly, I examine the nature of the constraints within which the regional and national economies operate. Thirdly, I consider the period-by-period effects of each policy in each region, so as to highlight the relative adjustment process of the regional economies.

I conduct two interregional policy analyses using a CGE framework: a broad-based demand-side and supply-side shock. Each of these relates to current policy concerns of the Scottish government. A third interregional application is intended as a methodological contribution to the research. In this paper, I assess the added value of a CGE versus an input-output approach to modelling the effects of a regional demand shock on another policy concern: the size of the CO_2 'trade balance' between Scotland and the rest of the UK. In a fourth policy application, I consider an additional issue related to the demand-side implications of current UK energy policy. In this paper, I examine the national economic impact of a demand stimulus that is associated with the development of a domestic and export market for UK renewable energy devices, in particular tidal energy turbines. This analysis is carried out in a national, and more highly disaggregated, CGE framework, and is intended as a precursor to an interregional analysis.

Overall, the results of the research highlight the existence and significance of interregional spillover effects, and differences in the relative adjustment processes of the regional economies. This suggests that a more inclusive analysis of devolved and regional policy could have a crucial impact on policy decision-making. Similarly, the analyses relating to regional and national aspects of UK energy policy make a significant contribution to the knowledge base for energy policy decision-making.

Chapter 1

Introduction

1. Background and motivation

The evaluation of public policy is a fundamental concern in economics. The process necessitates the comparison of outcomes that result from alternative policies, using a variety of different evaluation criteria. These comparisons often require estimating the effects of policies that have yet to be implemented, and the aim of this thesis is to conduct such ex ante evaluations of a number of distinct policy concerns of the UK national and regional governments. I consider the effects on the UK economy of a range of policy-induced regional or national shocks. A computable general equilibrium (CGE) framework is used for the analyses. For the regional policy analyses, I use an interregional CGE model of the Scottish and rest of UK economies, and for the analysis of a national policy shock I use a CGE model of the UK economy in which the regions are not separately identified. The model frameworks are designed to capture the interlinkages and feedback effects between sectors and, where relevant, between the regions of Scotland and the rest of the UK (RUK). Each of the simulations is intended to reflect the anticipated outcome of a specific policy which corresponds to current government policy concerns. These involve either supply-side shocks (for example an increase in labour productivity) or demand-side shocks (such as an increase in exports related to growth of the renewable energy industry).

One particular focus of the research relates to UK policy-making in the context of a devolved institutional framework. During its time in office, the UK Labour government has embarked on a programme of devolution and delegation of decision making and responsibility for some aspects of economic policy. The outcome of this process is that some policy decisions are taken at the regional level: in England, by the appropriate Regional Development Agencies; and in the RUK, by the elected regional government or local assembly. This arrangement raises some issues for regional policy evaluation: any changes in economic policies at the regional level may, and likely will, have accompanying spillover effects on the non-target regions, and vice-versa. The degree of openness of the UK regions means that these effects could be significant.

Despite the move towards decentralised policy decision-making and responsibility in the UK, there exists a general lack of understanding of the impact of regional development initiatives beyond the immediate policy target area. A substantial body of literature considers the effect of UK regional policy on the recipient regions (Taylor, 2002; Wren, 2003). However, studies that address the impact of regional policies on the non-target regions and/or the economy as a whole are far less common. In fact, until recently, the official Treasury position was that there could be no net national gains as a result of regional investment: any policy-induced increase in employment in one region would be displaced by a corresponding number of jobs elsewhere (HM Treasury, 1997). The scale of interregional effects was therefore assumed to be known ex ante. Consequently, regional policy was viewed as being concerned with distributional effects, rather than increasing aggregate employment and output. This official assumption of 100% crowding out is likely to have played a role in the deficiency of interregional or national analyses of UK regional policy in the wider research arena.

In recent years, however, the Treasury's position on the issue has become more ambiguous. Government policy evaluation documents now acknowledge the possibility of national efficiency gains arising from supply-side policies, though at present there is no explicit recognition of the potential for positive national effects associated with demand-side regional policies (HM Treasury, 2003). This has important implications for policy analyses of the type carried out in this thesis. As Taylor (2002, p. 204) states: "The 'big' question is whether regional policy yields economic benefits for the economy as a whole. We need to know, for example, whether the *non*-assisted areas benefit from regional policy and, if so, to what extent". Thus a proper evaluation process requires a full spatial impact assessment of the policy effects.

Despite the apparent shift away from assuming full crowding out with regards to regional policy, there does not seem to be any change in emphasis in the Treasury's regional policy evaluation process in practice. Official Treasury guidelines for the evaluation of national and regional policies provide no direction regarding how to identify or measure national efficiency gains; they demonstrate little explicit acknowledgement of the individual regions operating as an integrated system; and there is no consensus on how to appraise the net cost or benefit of the regional policy from a national perspective[1]. In this research, I aim to address this issue by adopting a more comprehensive study of the potential economic consequences of selected UK policies. Four policy analyses are carried out in total in the research; three of which are policy-induced economic shocks that are applied at the regional level. For each of these three applications, a more wide-ranging evaluation of the regional and national effects requires a number of tasks. Firstly, I identify the full spatial impact of the policy. I examine the nature and degree of interregional interdependencies, and estimate both the regional and national impacts of the policy shocks. Secondly, I specify the characteristics of the constraints within which the national and regional economies operate. In particular, I consider the impact of a population constraint by incorporating alternative hypotheses regarding the configuration of the regional and national labour market. Each of these is intended to represent a popular view of how regional labour markets work, and to reflect a different assumption about the nature of the population constraint. The third issue I consider is the period-by-period adjustment process of the regional economies in response to the exogenous shock. In the UK, the Treasury adopts a ten year time horizon for the evaluation of regional development policy (HM Treasury, 1995). In this thesis, however, I consider the longer-term period-by-period effects of each policy in each region, so as to highlight the relative adjustment process of the regional economies over time.

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[1] For more detail and discussion, see: HM Treasury et al. (2003); Learmonth (2003); McVittie and Swales (2007).

An array of modelling strategies can be used to perform policy analysis, and the choice of CGE framework in this thesis is driven by the key objectives of the research. CGE analysis provides a theory-consistent approach to modelling ‘what if’ policy scenarios, allowing for a data-driven, multi-sectoral account of the impact of policy disturbances in the economy. The technique has made a significant contribution towards achieving a greater understanding of the structure and evolution of spatial systems in economics, and so it provides a particularly useful technique for modelling the complex interlinkages and feedback effects amongst sectors and regions that are an important aspect of this study. The benefit of the CGE approach as a key modelling technique for policy analysis is confirmed by the proliferation of models used by international agencies such as the World Bank, OECD and United Nations, amongst others[2].

2. Thesis structure

The presentation of the research in this thesis is structured as follows. In Chapter 2 I commence with a review of the literature on CGE analysis, and an evaluation of the CGE modelling methodology. In the literature review section, I consider the theoretical background of CGE modelling and provide a description of a typical CGE model design for a national and interregional economy. Since the CGE technique can be applied to a wide range of problems in a multitude of circumstances, the literature on CGE modelling is vast, and a comprehensive examination of existing research is beyond the scope of this thesis. Therefore in Chapter 2 I discuss aspects of some key CGE models that have been used extensively for various policy issues, and some of their important applications. I also focus more closely on selected literature that is particularly relevant to the policy applications of this thesis.

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[2] See, for example: Anderson et al. (2006); Bora et al. (2002); and Bosetti et al. (2009).

In this chapter, I also evaluate the methodology of the CGE approach in order to emphasise the strengths and weaknesses of CGE models for policy analysis, and discuss the benefits of the technique relative to alternative modelling strategies that could be used for policy evaluation.

Overall, I find that the technical sophistication of CGE models, alongside the flexible operation of the framework, make it a very useful tool for the ex ante investigation of public policy impacts of the kind studied in this thesis. However, this chapter also acknowledges that, like all modelling techniques, there are inherent weaknesses in the CGE approach. The crucial issue concerns the type of analysis and the objectives of the policy evaluation: when used appropriately, the method plays an important role in informing policy design and appraisal.

In each of Chapters 3 and 4 I focus on the potential economic impact of a broad-based public policy initiative that is applied to the Scottish economy, and which reflects current policy concerns of the Scottish government. Each of the evaluations is carried out using an interregional CGE model of Scotland and the RUK, AMOSRUK [3], where the interregional linkages operate through trade and income flows and population migration. Chapter 3 examines the interregional effects of an exogenous increase in manufacturing exports in the Scottish economy. These simulations are intended to represent the consequences of the successful implementation of one of the key policy objectives of the Scottish government and Scotland's economic development agency, Scottish Enterprise - to increase Scottish exports by improving Scottish international competitiveness (Scottish Government, 2007a). In this chapter, I do not consider at length the ways in which such an export shock could be successfully induced by specific policy changes, though the final chapter of this thesis does look at a more specific export

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[3] AMOSRUK is an acronym of A Macro-micro model Of Scotland and the Rest of the UK. It is an interregional extension of AMOS, A Macro-micro model Of Scotland (Harrigan et al., 1991). Harrigan et al. (1991) gives a full description of early versions of the AMOS framework, and Gillespie et al. (2002) describes the interregional model AMOSRUK. Full model details are presented in Appendix A, and a summary version of the model is provided in Chapter 3.

demand shock, applied at the national level, in a more sectorally-disaggregated framework, as a means of exploring the particulars of the policy in more detail. In Chapter 4 I explore the region-wide consequences of a supply-side shock that is applied only to the Scottish economy: an increase in labour productivity in the Scottish traded manufacturing sector. This policy change relates closely to the direct impact anticipated from another of the policy priorities identified by the Scottish government: increasing labour productivity (Scottish Government, 2007a). Again, I do not explicitly consider specific policies that could potentially achieve this effect; rather I concentrate on the economy-wide, region-wide adjustment processes of the economy in response to the shock. Nor is the cost of such a policy considered – it is simply assumed to represent the costless outcome of more effective policy delivery at the regional level.

In these interregional analyses, different types of labour market scenarios are considered, thus reflecting a range of opinions about how the regional macroeconomic structure and the national constraints of the system operate. The labour market configurations combine different views concerning wage setting behavior and the mobility of the labour supply between regions, and thus the simulations incorporate different assumptions regarding the interaction of the regional economies. A number of variants of the AMOS and AMOSRUK models have been used in earlier research on both demand and supply-related issues, but in Chapters 3 and 4 I build on the existing research in a variety of ways, including: use of an updated dataset; exploring a wider range of labour market closures and interregional linkages than previously studied; and analysing the period-by period response of the regional economies following the shock. The latter aspect provides important information about the adjustment process of the economies, rather than the long-run equilibrium outcome only. More detail regarding the specific contribution to the literature for each of these chapters is provided at the outset of each of the chapters.

The results of the simulations highlight that regional policy, operating either on the demand-side or the supply-side, can have significant spillover effects at the national level. The configuration of the regional labour market and migratory behaviour do appear to be important factors in determining the magnitude of the stimulus and the adjustment path of the economy. Furthermore, I find that while target-region results are sensitive to the alternative assumptions of how regional labour markets function, the effects on the non-target region prove to be even more so. The adoption of an interregional framework is illuminating in that it highlights the different relative size of the effects on each region, as well as the dissimilar nature of the adjustment process back towards long-run equilibrium. This suggests that simply studying the economic effects on the target region could be misleading for policy decision-making. I also find that incorporating a time element into the study, rather than focusing on long-run equilibria only, highlights a number of important policy issues. Firstly, that the response of the economy is slow, and that there are often significant effects that occur outwith the Treasury's stated ten year time horizon for considering the effects of regional development policies. Secondly, I find that the relative effects of the policy shocks differ for the regional economies not only in terms of the size and direction of the effects for some of the model specifications, but also with regards to the timing of the effects and the time taken to move towards long-run equilibrium.

In Chapter 5, I present a methodological contribution to the thesis research. Earlier in the thesis, in Chapter 2, I argue that a CGE framework is preferable to an Input-Output (I-O) framework for the purposes of ex-ante analyses of economic disturbances, and Chapter 5 provides an explicit demonstration of the added value of the AMOSRUK CGE framework compared to a specific interregional I-O model in relation to one particular policy issue. I consider a current policy concern of the national and regional UK governments: the effects of changes in aggregate economic activity on the CO_2 'trade balance' between the Scotland and the rest of the UK. As a result of international initiatives such as the Kyoto protocol, there is currently a great deal of interest in accounting for carbon emissions that are associated with energy use reflecting economic activity, and techniques such as carbon footprinting have become popular methods of measuring the pollution content embodied in the consumption of goods and services. Consequently, environmental policy initiatives exist at the national level, reflecting the UK's commitment to such international agreements, and the Scottish government has also set its own, distinct (and more demanding) policy targets for reducing carbon emissions[4]. The existence of close trade linkages between two such economies means that attention has also focused on the allocation of responsibility for pollution emissions associated with goods that are consumed in one region but produced in another. It is this concept of a CO_2 'trade balance' – a measure of emissions spillovers between two economies that results from trade flows – which I explore in Chapter 5. In particular, I consider the impact of an exogenous regional demand shock on the key economic variables in the region and the economy as a whole, as well as the resulting change this exogenous shock has on the CO_2 'trade balance' between Scotland and the RUK. In doing so, I compare the results from a CGE framework with that of an I-O model, both of which are based on a common I-O dataset, in order to highlight the added value of a CGE framework in this particular context[5].

As expected, I find that the CGE approach, with its less restrictive modelling framework and ability to track the adjustment path of the economy over time, provides a more valuable contribution to the policy knowledge base compared to I-O modelling alone. I also find that the alternative specifications of supply-side behaviour at the regional and national level that are considered – in the form of alternative assumptions regarding wage determination and labour supply migration that are also considered in earlier

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[4] Whilst the Scottish and UK governments have set equivalent targets for the reduction of green house gases by 2050 (of 80% compared to 1990 levels), the Scottish Parliament's 2020 target of a 42% reduction is more ambitious than the UK government's target of 34%. For details of the Scottish and UK targets, respectively, see: Scottish Parliament, 2009; and Committee on Climate Change, 2008.

[5] In this chapter I make use of I-O simulations and pollution attribution calculations which are drawn from a separate study (of which I am a co-author; see Turner et al. 2009). These parts of the research are not intended to be an examinable component of this thesis, and are included for the purposes of comparison only. The contribution of this chapter to the PhD research is the CGE simulations and analysis, which is carried out with the objective of demonstrating the added information content of the CGE results relative to that of the I-O methodology.

chapters – affect not only the economic responses of the regions but also the impact on the interregional CO_2 'trade balance'.

The numerical results of the analysis in this chapter are qualified on a number of counts. These relate in particular to estimated and experimental data which are incorporated into the model datasets, and which may distort the model results. Thus I treat the quantitative findings of this part of the analysis as being preliminary in nature. Rather, the purpose of this chapter is to consider the contribution of CGE modelling to informing policy issues concerning the analysis of the pollution content embodied in trade flows related to regions' consumption of goods and services.

In the final applied paper, presented in Chapter 6, I consider a different issue, but one which is also related to the demand-side implications of UK energy policy. Alongside CO_2 reduction targets, UK energy policy emphasises the use of local renewable energy resources as a means of improving the security of energy supply and reducing carbon emissions. Furthermore, the UK and Scottish governments recognise the concentration of natural resources for the production of electricity from renewable sources that are available in the UK, such as marine energy sources, and that there are potential economic benefits to the UK from the development of a successful renewable energy industry. This provides the motivation for the research in Chapter 6, in which I consider the effects of a UK economic stimulus that results from the establishment of both a domestic and an export market for UK tidal energy technologies and devices. In this chapter, I simulate a series of domestic and export demand shocks in a single region, highly disaggregated CGE model of the UK economy, UKENVI, whose structure and characteristics draw some parallels with AMOS and AMOSRUK.

The size and time path of these domestic demand shocks are informed by various detailed industry estimates of the potential resource and installation capacity of tidal power in the UK, and of the potential expenditures associated with the manufacture and installation of tidal devices. To estimate the size of the export shock, in the absence of observed data or industry estimates, I draw on evidence relating to the Danish wind turbine export market. This provides some insight into the potential size and nature of an export shock for UK-manufactured tidal devices.

The results show that an increase in activity in the tidal turbine industry would have a positive, though modest, impact on UK aggregate activity, and that assumptions concerning the degree of local sourcing of the component parts of the turbine manufacturing process have a significant impact on the results.

This study is carried out at a UK level, though it is intended as a precursor to a more detailed interregional analysis of the issue. A more spatially-disaggregated study would be an important issue to consider because a disproportionately large share of the tidal resource is located in Scotland, and, if this concentration of the natural resource leads to 'clusters' of manufacturing activity in close proximity to the actual installation areas of the domestic devices, then the degree of both the domestic and the international component of the demand shock could be heavily skewed in favour of the Scottish economy. This could lead to important implications for interregional interactions and, in particular, for labour supply issues at a regional level. At present, however, sufficiently disaggregated data do not exist in order to conduct such a detailed study at the interregional level for the UK.

In Chapter 7, I provide a summary of the thesis objectives, before highlighting the key conclusions and contributions of the research. In broad terms, the research contributes a useful knowledge base for economic decision-making with regards to the size, direction and timing of various policy-related economic disturbances. In particular, the regional policy evaluations acknowledge the full spatial impact of the policy-induced exogenous shocks, and highlight the need for a similarly comprehensive government evaluation of regional, including devolved, policies. Furthermore, the specific demand-side investigations relating to the UK interregional CO_2 'trade balance' and the impact of the development of an export market for a specific renewable energy device provide more detailed insight into issues which are prominent and current concerns of both the UK and Scottish governments. Such matters have not been explored in this way in a UK context before, nor, to my knowledge, on an international basis.

I also discuss future research opportunities and potentially beneficial extensions to the thesis as a whole in Chapter 7. Drawing on the recent advances in the literature that are highlighted in Chapter 2, I note the key technical constraints that could be addressed to add value to the existing model structures used in the analysis, as well as issues regarding parameterisation, disaggregation, model specification and application possibilities that would further enhance research into the regional and national impacts of spatially differentiated policies. Finally, Appendices A-H contain model details, simulation results and other supporting material for the research[6].

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[6] Where reasonable to do so, I present tables and figures in the main text of each chapter. However, some tables and figures are referred to often at different places within the text, and for sake of readers' convenience and ease of comparison, these figures and tables are placed together in an appendix. Near the start of each chapter, I inform the reader of the location of all charts and figures for that chapter.

Chapter 2

CGE Modelling for Policy Analysis: an Evaluation of the Methodological Approach and a Review of the Relevant Literature

1. Introduction

In this chapter I provide a critical review of CGE analysis, which is the modelling technique used as the basis for the research in this thesis. The discussion proceeds as follows: I begin by explaining the theoretical principles underlying CGE modelling in Section 2, and follow this with a description of the characteristics and key components of a ‘typical’ CGE model in Section 3 (whilst acknowledging that the structure and key features of CGE models now vary widely). In Section 4, I go on to review the CGE literature that is most directly relevant to the research of this thesis. Applications of CGE models are not only vast in number, but the range of model specifications and applications also differ considerably. This therefore necessitates a selective approach to reviewing the literature. I consider various applications which are significant in terms of their model features or type of analysis, and go on to discuss recent major advances of the approach in Section 5. I provide an evaluation of the benefits and limitations of the CGE modelling strategy for policy evaluation in Section 6, and highlight the added value of the technique compared to other traditional, and not so traditional, approaches to national or interregional economic analysis in Section 7. I present concluding comments in Section 8.

2. Theoretical background: the basic structure of a general equilibrium model

Underlying the CGE methodology is the Walrasian general equilibrium structure (Walras, 1926), which is expressed in mathematical terms as a system of simultaneous equations representing market equilibrium conditions, where an equilibrium is characterised by a set of prices and levels of production in each industry such that demand equals supply for all commodities simultaneously[1]. This framework was first formalised in the 1950s by Arrow, Debreu and others, who specified the necessary conditions for a competitive equilibrium to exist[2]. Throughout the 1960s, leading general equilibrium economists developed and refined propositions on the existence, uniqueness, optimality and stability of solutions to general equilibrium models (Arrow and Hahn, 1971). These models were expressed in general, algebraic terms, and such general equilibrium analysis remained theoretical in nature until the 1970s.

Scarf's work (1967a, 1967b) is widely credited as being the catalyst for the transformation of the general equilibrium model from a purely theoretical framework to an operational model that could aid policy decision-making[3]. He not only contributed to general equilibrium theory (Debreu and Scarf, 1963), but more importantly designed an algorithm for computing solutions to numerically specified general equilibrium models, drawing on the mathematics of the theoretical existence theorems (Scarf, 1967a, 1967b; Hansen and Scarf, 1973). This ground-breaking technique for the explicit computation of equilibrium prices established a new field within the general equilibrium discipline – the study of applied or computable general equilibrium (AGE/CGE) models, and Scarf acknowledged that his solution techniques "[...] might be useful in assessing consequences for the economy of a change in the economic environment" (Scarf 1967b, p.11). His students extended the Scarf algorithm into a 'tool box', such that the equilibrium price vector could be solved for any changes in exogenous variables or policies, giving the economic 'adjustments' required for that equilibrium. This

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[1] Shoven and Whalley (1992) set out the basic principles in more detail.

[2] Arrow and Debreu (1954). Debreu (1959) and Arrow and Hahn (1971) extend this work. Greenaway et al. (1993) provide an accessible version of the proof of existence of a general equilibrium.

[3] Arrow and Kehoe (1994) discuss Scarf's contributions to AGE research. In recognition of Scarf's election as Distinguished Fellow of the American Economic Association in 1991, the citation by the American Economic Review reads, in part: "Scarf's path-breaking technique for the computation of equilibrium prices has resulted in a new subdiscipline of economics: the study of applied general equilibrium models. His students and a larger number of other researchers have applied general equilibrium models to issues such as the analysis of tax reforms, trade policies, economic integration and development. Scarf was the catalyst behind the creation of this subfield of the profession and in the transformation, of the general equilibrium model from a purely theoretical construct to a useful tool for policy analysis", available at: http://cowles.econ.yale.edu/news/scarf/hes_92-09_dfellow.htm.

methodological revolution in general equilibrium analysis attracted a number of researchers to further develop its applied dimension[4].

While Scarf's (1967a, 1967b) contributions are a notable and important step in the conversion of general equilibrium theory into a practical tool for the numerical evaluation of economic policy, Johansen (1960) is credited with devising the first CGE model that is based on the premises of general equilibrium theory (Dixon and Parmenter 1996). His model of Norway was a whole-economy linear model that could be solved with simple linear algebra. The beginnings of this type of CGE framework started with the work of Leontief in the 1930s at the Bureau of Labour Statistics (BLS), when Leontief set up an Input-Output (I-O) model for the US economy. He constructed an 'economy-wide' accounting system, which incorporated all industries and private individuals, resulting in the first 'complete' statistical overview of the flows and sources of funds in an economy. The BLS used this I-O framework to forecast post-war steel demand[5]. The forecast using the I-O model was one of the few to indicate that steel demand would not fall in a post-war scenario, but would be strong. Other forecasts suggested that steel plants would likely close since they would no longer supply the armament industry, but these forecasts neglected the potential for other-sector effects. In contrast, the existence of inter-industry linkages in the I-O model meant that researchers were able to identify consumers' pent-up demand for appliances and cars, which were also made of steel, and that steel plants would have to expand to accommodate this (Duncan and Shelton, 1978). The I-O forecast turned out to be correct, and this factor is argued as being the reason why multisector I-O analysis became an important form of economic analysis to government administrations and academia (Leontief, 1951). Chenery and Clark (1959) later incorporated new behavioural functions and demand systems into Leontief's framework, using the model to simulate whole-economy responses to changes in variables, in particular the

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[4] Kehoe et al. (2005) provides a comprehensive account of the contributions to this particular area of research.

[5] The I-O estimates remain unpublished, but are referred to by Leontief in 'The New Palgrave: A Dictionary of Economics' (Eatwell et al., 1987) in the section on 'I-O Analysis'.

'interdependence between the productive factors of an economy' in relation to development policies (Chenery and Clark, 1959).

Johansen (1960) independently formalised this approach into a consistent framework, which came to be known as CGE modelling. In doing so, he built a 'fixed output stochastic model' around a benchmark data set for Norway for 1950 – a matrix form of the national accounts data of that year, in the spirit of an I-O model. He assigned demand and production functions to the consumer and producer sectors, defined trade elasticities and allowed for labour and capital mobility. He assumed full employment for capital and labour, exogenously fixed exports and investments, and defined the requirements of an equilibrium. To use the model for economic analysis, he made changes to the exogenous variables in order to simulate a change in economic conditions, and used linear approximations to derive the counterfactual solution from the initial equilibrium. Since he was using data from 1950, and writing in the late 1950s, he was able to compare simulated results with empirically observed data for later years, to check whether the elasticities and changes to variables corresponded to actual economic data, in order to explain "relationships in Norwegian reality" (Johansen, 1960, p.3). The model proved successful, despite what he termed unrealistic assumptions of suppliers operating in perfect competition and a marginal equality between wage rates and marginal values of output, which are both "realistically unknown" (Johansen 1960, p.171).

With increased empirical demands placed on models, traditional Scarf-type models later faded from popularity due to their high cost of computation and questions over their ability to provide a unique solution. Jorgenson (1984), commenting on the methodology of the early Scarf-type models, noted that "Implementation of econometric models of producer behavior is very demanding in terms of data requirements. These models require the construction of consistent time series of interindustry transactions tables. By comparison, the non econometric approaches of Leontief and Johansen require only a single interindustry transactions table" (Jorgenson, 1984, p.141). By the mid 1980s, users of the Scarf approach began to incorporate social accounting matrices (SAMs)[6] as their equilibrium data set (Mansur and Whalley, 1984)[7]. Today, the technique of both AGE and CGE modelling refers to "calibrating and benchmarking observed data on economies into an initial equilibrium data set and then doing counterfactual policy analysis" Kehoe et al. (2005, pp.1-2), and the terms are used inter-changeably in the literature[8].

3. A typical CGE model design

In this section, I present an example of a simple, stylised, theoretical general equilibrium model[9]. Firstly, I outline the elements of a 'classic' national CGE model. I then summarise the additional characteristics of an interregional framework.

3.1 General model structure

A CGE model is an analytically consistent mathematical representation of an economy. The basic structure is straightforward – it comprises a detailed database of actual economy-wide data which captures the interdependencies across all sectors in the economy at a particular point in time, and a set of equations describing model variables. These equations tend to be neoclassical in spirit; households maximise utility subject to a budget constraint, and firms maximise profits (minimise costs). This gives rise to demand and supply functions, derived in accordance with consumption and production theories.

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[6] A SAM is an augmented I-O table with transfer payments between economic agents and factors of production, and covers all domestic and international transactions in the economy that year. See Section 3.9.1 for further detail.

[7] Mansur and Whalley (1984, p.87) state that "[A] micro consistent equilibrium data set is constructed using national accounts and other sources for the purpose of both making the comparison possible and to provide a data base for model calibration".

[8] For example, Devarajan and Robinson (2005, p.1) "use AGE and CGE as synonyms".

[9] Many of the model features identified are common, but not essential, characteristics of a CGE model.

Many CGE models are similar in that they tend to: be static, have two factors of production (labour, which may be disaggregated by skill level, and capital); have a limited number of commodities; and model inter-industry linkages using I-O fixed coefficients from an accompanying SAM database. In addition, the assumption of constant returns to scale for production technologies is often used to facilitate an equilibrium concept upon which to base the analysis. However, these are by no means the defining characteristics of a CGE model. A number of factors influence the common features, including the availability of data and solution techniques, but the precise structure of a CGE model is determined largely by the intended use of the model.

The models are solved computationally, with an equilibrium being characterised by a set of prices and level of production across all sectors such that demand equals supply for all commodities simultaneously. The framework is used to estimate how an economy might react to changes in policy or other exogenous influences, and the counterfactual solutions provide qualitative and quantitative estimates of the impact of specific policies or effects on the allocation of resources and the relative price of goods and factors.

3.2 Households

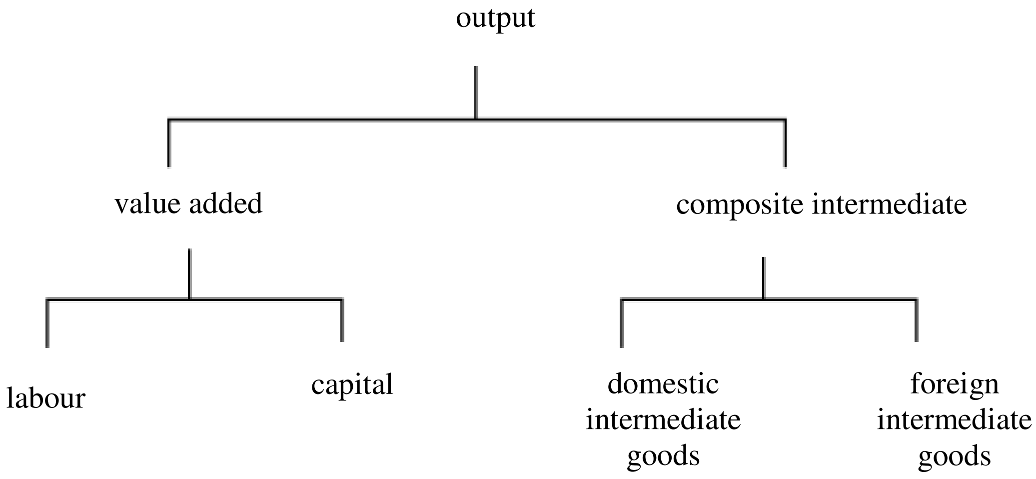
Households are both consumers and owners of factors of production. They receive income from factor payments in the form of rent on capital and wages (and any other income streams, depending on the number and type of factors included in the model framework). This income is used to pay for households' consumption of goods and services (and for tax payments or savings, again depending on the exact model description). Consumption generates utility for households, and households decide how much of their income to allocate across goods and services with the objective of maximizing utility subject to their budget constraint. This utility maximization problem is most often posed in terms of a representative household.

3.3 Producers

In the production sector, there is a set of inputs to production, a designated production technology, and a set of outputs. Profit maximising (cost minimising) firms make supply decisions using the prices of goods and factors of production as market signals. Primary factors are purchased from households; intermediate goods from other firms. These are used to produce outputs which are, in turn, purchased by households. Sales revenues are used to pay the owners of factors of production and the suppliers of intermediate inputs. Perfect competition ensures that no economic profits are made in equilibrium.

Figure 2.1 illustrates an example of a nested two-level production technology structure. The production technology is often divided into two levels – intermediate and final goods. At the intermediate level, inputs to production are combined to produce a composite intermediate good. In addition, primary factors of production are used to produce value added. At the top level of the production hierarchy, the composite good and value added are combined to produce final outputs.

Figure 2.1 An example of a nested two-level production technology structure



3.4 Government sector

In a CGE model with a government sector, the role of the government is to receive income in the form of taxes and tariffs, to redistribute income in the form of subsidies and benefits, and to purchase goods and services. Unlike the activity of consumers and producers, which is explicitly optimization-based, government activities tend to be used to impose exogenous changes on the model, in the form of policy shocks.

3.5 Choice of functional form

The selection of utility and production functions is partly determined by the requirements of theoretical consistency and analytical tractability. Whilst the functions are required to meet the standard constraints of a general equilibrium model, such as market clearing and normal profits in all markets (though see Section 3.8 for a discussion of non-neoclassical model closures), they also need to generate production and expenditure patterns that can be easily evaluated at the equilibrium. As a result, ‘well-behaved’ functional forms such as the Cobb-Douglas or Constant Elasticity of Substitution (CES) forms are often used.

3.6 Degree of aggregation

The choice of the level of aggregation is also determined by the purpose at hand, as well as data availability. Even in the case of an abundance of data, there exists a trade-off between using a highly disaggregated data set in order to achieve more detailed model results, versus the associated computational difficulties of doing so, and the complexities involved in interpreting a substantial volume of results.

3.7 Trade

International or interregional trade may be incorporated into a CGE model, both in terms of trade in intermediate inputs and composite commodity outputs. For intermediate inputs, it is necessary to specify the elasticity of substitution between imported foreign or other region goods and domestic goods. Almost all CGE models incorporate an Armington (1969) assumption for this purpose. This assumption differentiates products by country or region of origin, so that cars produced in Germany, for example, differ from cars produced in the US[10]. Therefore, even in the case of free trade between the economies, world prices for US and German cars do not need to be equal, allowing each country to simultaneously import and export cars. Without this assumption, the existence of perfect competition and homogeneous products would mean that for individual commodities, the economy could only be self-sufficient, exporting-only or importing-only. Such 'law of one price' models are characterised by extreme specialisation and sensitivity to relative price changes.

The Armington assumption has implications for producers' and consumers' decisions. For firms, some of their intermediate inputs will be imported, and the choice over imported or domestic inputs will depend on their relative prices, as well as the Armington elasticity. For consumers, some goods will be a composite of imported and domestic inputs. Similarly for the consumer, the choice over imported and domestic goods will depend on relative prices and the Armington value.

3.8 Model closure

The number of endogenous variables for which the CGE model can obtain a solution is clearly constrained by the number of independent equations. Accordingly, this requires

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[10] Some models do incorporate monopolistically competitive features and increasing returns to scale, often in the manufacturing sector (e.g see: Brown, Deardorff and Stern, 2003; Francois, van Meijn and van Tongen, 2003). The notion is that some products are differentiated according to their individual features, rather than their country of origin.

that a number of model variables are specified as exogenous, thereby determining the model closure. This choice reflects the (primarily macroeconomic) assumptions within which the policy analysis is set, and therefore depends on the nature of the issue being addressed.

Although a 'classic' CGE model yields a full-employment equilibrium with market clearing prices, many researchers impose alternative macroeconomic closures on the framework. These exemplify some necessarily ad hoc assumptions concerning the characteristics of agents or markets, so as to impose more realistic macroeconomic behaviour on the neoclassical framework. These features include, for example, wage and price rigidities, partial adjustment mechanisms and non-market clearing equilibrium outcomes.

In particular, various model closures are often used to represent different assumptions about the operation of the labour market. To represent an assumption of involuntary unemployment, for example, the researcher may set employment as endogenous and exogenously fix wages at an above-equilibrium rate. Alternatively, a full employment, perfectly flexible labour market assumption may be represented by a model closure that sets wages as endogenous with and employment as exogenous so as to reflect the fixed labour supply of the economy.

This practice, of course, raises the issue of the different notions of equilibrium in macro and general equilibrium models (discussed in Malinvaud, 1977), and some authors explicitly criticise the combination of macroeconomic and Walrasian elements that are found in a multitude of CGE models (see: Bell and Srinivasan, 1984; Srinivasan, 1982). A discussion of this topic is outside the remit of this research, but Rattso (1982) and Robinson (1991) provide a survey of the debate.

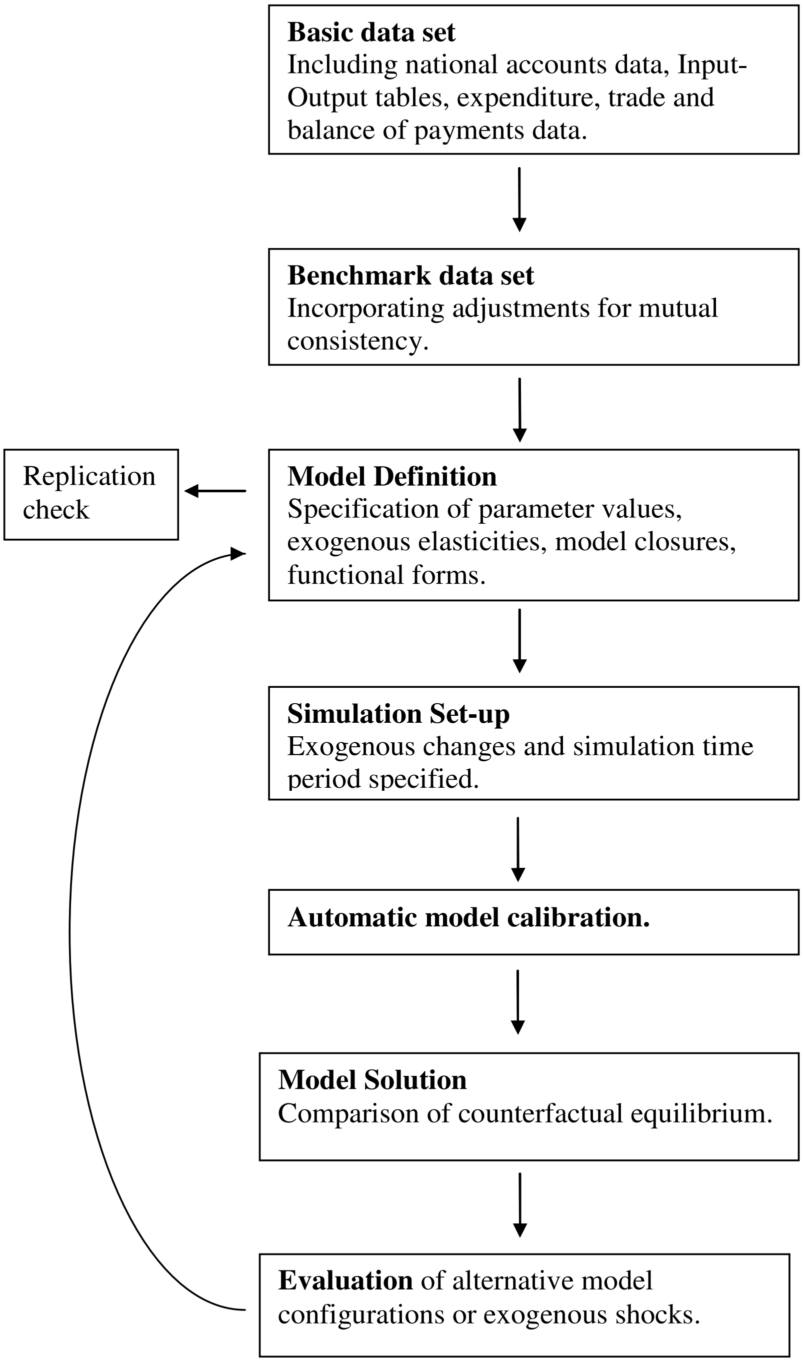
3.9 Operationalising the model

3.9.1 Benchmark data and parameterisation

Figure 2.2 summarises the various steps involved in parameterising, specifying and simulating a CGE model. The key first step towards operationalising a CGE model involves selecting a benchmark data set, typically a SAM. This describes the characteristics of an economy for a representative year, highlighting the linkages that exist between sectors and regions. A SAM is an augmented I-O table with transfer payments between economic agents and factors of production, and covers all domestic and international transactions in the economy that year. The SAM incorporates a number of sources of information: the I-O table for the economy; national accounts data; government accounts; balance of payments data and trade data. The I-O table contains production sector data, including sectoral linkages in the economy, and the contribution made by the primary factors of production. The national accounts disaggregate demand into consumption, investment, governments spending and exports and imports. The trade accounts provide detail on the composition and destination of exports and imports, and government accounts provide information on public expenditures and revenues.

The structural data embedded in the SAM are used to ascribe actual values to some of the parameters of the functional forms in the model system, for example the relative size and import intensity of sectors. The exogenous parameters are then imposed, informed by available data and existing studies. These parameters characterise the behaviour of producers and consumers in the model, and describe the responsiveness of producers and consumers to changes in relative prices and income. They include, for example: the elasticities of substitution in value added, thus determining the substitutability of labour and capital inputs to production; the demand and income elasticities of households and consumers; and the Armington elasticities that describe the elasticity of substitution of domestic and imported composites. Other parameter values, such as migration function parameters, can be determined exogenously by drawing from existing literature.

Figure 2.2 Procedures for CGE model operation



Source: adapted from Greenaway et al. (1993), p.23.

3.9.2 Calibration

A final set of parameter values are determined through calibration of the model for the set of remaining unknown variables. This involves fitting the model to the benchmark data set: the remaining parameters are chosen and adjusted deterministically so that, together with the SAM data and the values of the behavioural parameters, the model is able to reproduce the benchmark data set.

3.9.3 Model simulation and equilibrium solution

Once the model is fully specified and parameterised, it can be used to simulate the effect of a policy shock or an exogenous change in economic conditions by specifying new values for policy instrument(s) or economic variable(s) of interest. The model is solved for a unique set of prices that identifies a new market equilibrium, where an equilibrium is characterized by the equalization of demand and supply across all markets simultaneously. Different settings for the exogenous variables will produce different market equilibria, and it is therefore possible to evaluate the effects of alternative policy changes or economic shocks. Each policy change is associated with an equilibrium, allowing for direct comparison amongst policy alternatives.

The simulation outputs are used to analyse the effects of the exogenous change on the endogenous variables of the model – consumption, production, prices, exports, imports and so forth, and/or the impact on welfare, depending on the model specification[11]. The simulation results illustrate what the economy would look like if the exogenous shock were to take place, and the difference between the simulated response of the model variables and the base year data represents the effect of the policy or exogenous change.

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[11] CGE models are also often used to measure the impact of policy changes or exogenous shocks on economic welfare, using Hicksian compensating or equivalent variations measures, for example. Greenaway et al. (1993, p.24) summarises the steps involved in these calculations.

3.9.4 Interregional CGE models

Interregional CGE models are designed to provide an understanding of the interactions amongst regions and a quantitative representation of the spatial economic system. There are two approaches to constructing an interregional CGE model: the ‘top down’ approach and the ‘bottom up’ approach, and the choice between each model type usually reflects a trade-off between data requirements and theoretical sophistication[12]. The top-down method involves the use of national CGE model results, which are then disaggregated to a regional level on an ad hoc basis. The mapping of the economy-wide results to a regional dimension takes place without any feedback effects from the regions, and there is no explicit modelling of the behavior of agents at the regional level. As such, the analysis of regional policies or regional economic shocks cannot be analysed within the framework. The reduced theoretical refinement of the model structure does, however, mean that they are relatively less data-demanding compared with the bottom-up approach.

In contrast, in a bottom up structure, regional agents’ behaviour is explicitly modelled, and a fully interdependent system allows national-regional feedback effects to occur in both directions. In contrast to the top-down approach, national results are obtained from the aggregation of regional results. The regional interlinkages can be modelled using regional estimates of trade (commodity flows) and factor mobility (in particular labour mobility). The data requirements are thus very demanding, and necessitate use of an interregional I-O database, interregional trade elasticities and other variables, for which regional econometric estimates are not often available. However, this type of structure can be used for analysing the effects of disturbances that originate in the regions, and are therefore better suited for detailed regional policy evaluation.

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[12] See Liew (1984) for a discussion.

The degree of interaction between regional markets can differ across models. Factor mobility plays an important role in determining the extent and characteristics of interregional relationships. Factors can be allowed to move across sectors and regions. Labour supply has received most focus from researchers, with labour migration motivated usually by wage differentials. Capital is normally assumed to be immobile between regions in the short-run and, where permitted, long-run capital movements tend to be driven by sectoral and/or regional differentials on rates of return or productivity.

Another indication of the degree of ‘openness’ between the regional economies is reflected in the elasticities of substitution between similar commodities that are produced in different regions. An Armington assumption (Armington, 1969) is usually employed at the regional level, as well as for the specification of national trade. This allows for trade between regionally-produced products and similar products from other region(s), and also between domestically produced products and similar products from other countries. Econometric estimates for the interregional elasticities of substitution are, however, rarely available, and model users often have to extrapolate from national Armington elasticities.

Another important aspect of an interregional CGE model is the macroeconomic closure of the system. For single region models, the small-economy assumption usually holds. Interest rates and exchange rates are exogenously determined in the wider national economy. Extra-regional prices are exogenous, whilst regional prices are usually endogenous. Interregional models relax the assumption that the prices of other regions' outputs are exogenous. For an interregional model, regional prices and quantities are determined endogenously within the system, though the role of interest and exchange rates needs to be defined.

4. Literature review: national and interregional policy-related analyses

Advances in new algorithms and programming tools have made CGE modelling for policy analysis a vastly growing field in economics. The variety of policy issues on which CGE models have had an influence is extensive, and includes: tax reform; environmental and energy issues; international trade; agriculture; structural adjustment policies; and income distribution, among others[13].

Given that the number and range of applications is now huge, a comprehensive survey of the role of CGE models in policy formulation is beyond the scope of this chapter. Instead I focus attention on prominent formulations and applications which play a crucial role in the policy literature, as well as the features, applications or results of CGE models that are particularly relevant to the studies of demand and supply-side disturbances that I consider in this thesis. The review of literature is therefore selective, and is intended to provide some examples that help to inform the practical policy applications that I conduct in later chapters, particularly relating to small, open, developed economies. Despite the wide-ranging nature of the CGE literature, there are few studies that are closely comparable with the policy analyses in this thesis, particularly in a UK and interregional context. Therefore, I focus on a broad range of national and interregional studies of demand or supply-side shocks from the literature[14]. A number of related studies have previously been carried out using the AMOS framework and its model variants. Details of these are provided in each of the relevant individual chapters, alongside a description of the exact contribution of each study to the literature as a whole.

I first consider national CGE analyses, and focus, though not exclusively, on small open developed economies.

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[13] Devarajan and Robinson (2005) review the use of CGE models to influence public policy.

[14] In doing so, I mainly consider quantity-base policies (i.e policies that directly influence demand or supply), rather that price-base policies (e.g, taxes and subsidies).

4.1 National CGE policy analysis

The ORANI CGE model of Australia (Dixon et al., 1982) has been used extensively for policy analysis. Adaptations of the model exist for many countries including China, South Africa, North America and Brazil, though no ORANI model exists for the UK. Like the classic CGE models, it is derived from orthodox micro assumptions about the behaviour of price-taking agents. In the base model, there are 113 domestic industries, 115 commodities and 9 labour occupations. Various ‘add-on’ facilities allow the model to be adapted to suit the policy purpose (for example, extending the labour categories to up to 72 occupations or regionalising the model to the level of 6 Australian states[15]). Market clearing equates demand and supply for domestically produced commodities, though non-equilibrium notions, such as unemployment, can be accommodated. The modeller can define, for example, the conditions of the balance of trade, and alternative wage-setting scenarios and time horizons of analysis. These characteristics make it similar in spirit to the characteristics of the AMOS model and its variations which feature in the applied analyses of this thesis (described in detail in Appendices A and H), though more highly disaggregated.

There are numerous policy applications of ORANI. One study that is particularly relevant to this thesis is the ‘what-if’-type analysis of the effects of Australian demand-side policy in Dixon et al. (1979). The authors compare the strategy of domestic demand expansion versus wage rate reduction as a means of increasing aggregate domestic activity. Like the findings in this research (see Chapter 3), Dixon et al. (1979) show that a domestic demand expansion (with fixed wages) leads to a cost-price squeeze on the export sector, thereby worsening the competitive position of the external sector. The study is useful in highlighting issues that are relevant to the demand-side analyses in this thesis, such as the impact of policy on competitiveness, and the associated effects on aggregate activity, as well as the uneven sectoral impact of the policies. However, the

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[15] See Section 4.2 for more discussion of the interregional model variant.

research in this thesis also considers the results under various labour market configurations, as well as in an interregional context.

An additional CGE framework which is part of the ORANI line of models is MONASH (Peter et al., 1996). This is a 113-sector CGE model of Australia with extensions that allow the incorporation of up to 282 occupations and numerous types of households, and which has also been applied to other countries. Most aspects of MONASH correspond to, or are very minor developments of, the theory underlying the ORANI model described above (Dixon et. al., 1982)[16]. The key difference is that the treatment of capital accumulation and investment introduces some dynamic interactions into the framework that are absent in ORANI.

The capital adjustment process is similar in nature to that specified in the AMOS model and its variants, but differs in terms of the exact specification. In the AMOS framework, investment is equal to depreciation, plus some fraction of the difference between the actual and the desired capital stock, where the desired capital stock is a function of commodity output, the nominal wage and the user cost of capital. In MONASH, capital growth rates (and therefore investment levels) are determined according to functions which relate investors' willingness to supply capital to expectations about industries' rates of return on capital. Investors are cautious, so that the capital growth in any year is limited by investor perceptions of risk. Investors are willing to allow the rate of capital growth in industry j in year t to move above j's historically normal capital growth rate only if investors expect to be compensated by a rate of return on capital which is above the historically normal level of industry j. The capital supply functions place a limit on the growth in the industry's capital stock so that changes in the industry's rate of return are diminished gradually over time. Two treatments of expected returns are available within the framework: static and forward expectations[17].

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[16] All aspects of the MONASH model are described in Dixon and Rimmer (1997).

[17] For the forward-looking expectations specification, MONASH is solved iteratively, so that several solution sets for years t, t_{+1}, t_{+2} and so forth are computed.

Dixon and Rimmer (2002) use the MONASH model to describe the effects of a positive shock to the Australian manufacturing sector (specifically the motor vehicle industry). However, they look at the issue from a historical rather than an ex ante perspective. That is, they impose a number of exogenous changes in model variables in order to match observed data for actual changes relating to developments in the Australian motor vehicle industry over the period 1987 to 1994, with a view to describing ex post the economy-wide implications of the sectoral shock. The variables chosen are those which are assumed to be of direct relevance to the motor vehicle industry, including sector specific data observations (such as exports, output and capital stock in the motor vehicle industry), as well as those which refer to the broader economy, but which are assumed to be directly relevant to activity in the sector (such as national household consumption and investment in the transport sector as a whole). To allow the model to achieve these changes, the authors endogenise various other variables, including primary-factor-saving technological changes, intermediate-input-saving technological change, rates of return on industrial capital, and preferences for imported goods versus domestic goods.

This approach is in stark contrast to the analysis of a positive demand shock to the Scottish manufacturing sector that is conducted in this thesis. Whilst the subsequent papers in this thesis involve ‘what-if’ type policy analysis, the Dixon and Rimmer (2002) paper attempts to use the CGE framework to describe economic history. The authors aim to quantify the economic interlinkages underlying the specific shock, the size and characteristics of which is exogenously specified by observed data. In doing so, they assert that “MONASH [is] a framework for estimating changes in tastes and technology and for generating up-to-date I-O tables” (p.37). Whilst this use of the CGE model may be useful in a descriptive, ex post sense, it is perhaps less useful for policy-making, since the range of exogenous shocks that are imposed make it difficult to attribute either the sectoral or the aggregate implications to any one or any combination of variables that could be targeted by policy makers. The complexities associated with the linkages and feedback effects throughout the economy cannot be attributed to any one of the exogenous changes that are imposed. Furthermore, whilst the ex post descriptions may shed some light on past economic events, and may be useful to policy makers as part of a wider analysis, it may be difficult to have confidence in the quantification of the linkages being reliable I-O estimates, since the quantification of the sectoral linkages are estimated so as to replicate a specific exogenous shock, which is most likely only one part of the description of economic activity at the time. Other economic activities are most likely occurring simultaneously, and these would almost certainly affect the estimates, though they are excluded from consideration.

The MONASH model is also used for the purposes of forecasting. In another demand-side analysis, Adams et al. (2002) forecast the effects of a fall in export demand in the tourism sector following the September 11th terrorist attacks in the US. This analysis, more in line with the 'what if' research conducted in this thesis, imposes an exogenous reduction in the demand for tourism exports, and the economy-wide consequences are considered. A key difference with this approach and the analysis in this thesis, however, is that in Adams et al. (2002) the post-shock simulation results are compared to a base case counterfactual which incorporates exogenously determined macroeconomic forecast estimates for the economy, rather than a ceteris paribus base case scenario. In doing so, the authors exogenise macroeconomic variables which they suggest would otherwise normally be assumed endogenous (including, for example, estimates of consumer price inflation, investment growth, housing activity and sectoral employment) and shock them using various specialist estimates of macroeconomic forecasts. Correspondingly, the authors endogenise variables which they suggest would normally be exogenous (such as propensity to consume, invest and import and the position of export demand and supply curves). The impact of the shock is then calculated as the difference between the base case scenario incorporating the macroeconomic forecasts, and the simulated results which incorporate both the macroeconomic forecasts and the exogenously imposed estimates of the fall in exports relating to the tourism shock.

Szeto (2002) presents a CGE model for the New Zealand economy, and uses the framework more in line with the conventional practice for policy-type analysis. The effects of a number of economic shocks are analysed using 'what if' type questions, and no forecasts are included in the comparative static baseline for the simulations. The author uses an updated version of the CGE model developed for New Zealand by Murphy (1998), which is a three-good, small open economy model with four behavioural sectors (households, firms, the external sector and government), where households and firms maximise utility and profits respectively, along the lines of a typical CGE model. The production structure is econometrically estimated, using Maximum Likelihood, and includes two CES and one constant elasticity of transformation (CET) functions, whilst other parts of the model are calibrated. Employment is exogenous and wages are endogenised, determined by an inflation expectations augmented Phillips curve. The author highlights two key dynamic characteristics in the model. Firstly, households and firms adjust partially to the long-run equilibrium. Household consumption is modelled as a partial adjustment process, so that consumption depends on the relative price of imports, the yield curve (which itself reflects the fact that households will decrease consumption when interest rates rise and the return on savings increases, and vice versa), and the equilibrium level of consumption (which is determined by labour income and wealth). The rate of investment also adjusts partially to the benchmark rate, influenced by the difference between actual and required rates of return, and the slope of the yield curve. The second dynamic element is the incorporation of forward looking expectations. Monetary policy is explicitly modelled in the framework (the Central Bank adjusts short-run interest rates in order to achieve an inflation target) as is fiscal policy, and both adopt forward-looking rules. Financial markets are also explicitly modelled via incorporation of a bond market and equations that determine the equilibrium path for the real exchange rate.

Szeto (2002) separately simulates a range of shocks, each of which is designed to describe the mechanisms through which an exogenous change in a specified variable affects the wider economy. The author shows that an exogenous temporary demand shock in the form of stronger domestic demand fuels import growth and also export growth, via stronger investment growth. An increase in inflationary pressures leads to monetary tightening and this, together with an exchange rate correction, helps the economy to move towards long-run equilibrium. In the analysis, the role of monetary policy helps the economy to return to equilibrium. This is in contrast to the demand-side simulations using the AMOSRUK and UKENVI models in this thesis, where there is no active role for monetary policy. However, in Chapter 6, for example, I incorporate an exogenous labour supply closure within the national UKENVI model, and the long-run equilibrium in this case may correspond with that of a framework with an active role for monetary policy. This configuration implies a wage-inelastic labour supply function, such that the real wage continuously adjusts in order to equate aggregate labour demand and a fixed labour supply. Using this closure, I find that an exogenous demand shock also stimulates export and import growth, and that an increase in the real wage, and corresponding crowding-out effects, ultimately plays a key role in restoring equilibrium in the economy.

For the final paper in this thesis, I look at the economy wide implications of a scenario whereby the UK experiences a domestic and export demand shock related to an increase in demand for renewable energy production devices – specifically tidal energy turbines. At present, there are no examples in the literature of this kind of ‘what if’ study relating to the impact of the development of a domestic and export demand for turbine production. However, Perry (2008) presents a CGE application which is relevant to the research of Chapter 6. Perry (2008) considers the existence of a number of policies in place in the EU and the US to replace fossil fuels with biofuels, and analyses the potential for the Argentinean economy to respond to an increase in export demand for biofuel commodities (such as seed and vegetable oils). This is therefore an exogenous shock related to a development in a particular renewable energy sector in Argentina, though the type of analysis and key issues involved are quite distinct from those of Chapter 6 in this thesis. Firstly, the type of exogenous shock used in Perry (2008) is actually a price shock rather than a direct export shock of the kind introduced in Chapters 3 and 6 of this thesis; the author imposes an exogenous increase in the world export price of commodities related to biofuel production (such as seeds and vegetable oils), so as to pre-empt an increase in the supply of exports of these commodities[18]. Thus the price shock works through the rest of the economy in a different way than a demand shock. Secondly, one of the key issues in the biofuel industry is the importance of land use, and the crowding-out effects associated with using land resources for biofuel rather than food production. In contrast, land as a factor of production is not an issue that is directly considered in this thesis. Nevertheless, the paper highlights some important and relevant issues to this thesis.

The author uses a single region, comparative static SAM-based CGE model for the analysis. The model is a purpose-built CGE model, BioTrade Land, and is used in a conventional 'what if' sense to consider the economy wide effects of the expansion in world agricultural trade in biofuels. There are three factors of production in the economy: land, labour and capital. In the basic model, these quantities are fixed, so there are no population growth effects in the model, nor capital investment or land use change over time, and in a separate scenario analysis, capital and land are available in infinite supply. Producers can substitute between factor inputs, so that industries can become more land, labour or capital intensive, and CES functions are used to determine the extent of the substitutability of the factors. Constant returns to scale are assumed. A flexible exchange rate regime is incorporated so that an increase in the economy's exports leads to an appreciation of the domestic currency. In the basic simulation, land, labour and capital factors are fixed. Consequently, the author finds that in response to the exogenous world price shock, designed to simulate an increase in the export supply of biofuel crops, there is an increase in production in those sectors related to biofuel commodities, and that this crowds-out production of non-biofuel crops. There are small effects on non-agriculture sectors, and the overall effect on consumption is broadly neutral. In the scenario where the supply of both land and capital are assumed infinite

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[18] The Perry (2008) study does differ fundamentally from the analysis of an exogenous demand stimulus to the renewable energy sector that is considered in Chapter 6, but it perhaps draws closer parallels with the supply-side analysis of Chapter 4 of this thesis. In this chapter, I find that a regional labour productivity shock generates price and competitiveness effects due to an increase in the effectiveness of the labour supply.

over the medium term, the effects of the shock differ. The production of crops related to biofuels increases significantly more than in the base case scenario, and production in most other of the land-using sectors is crowded out to a much lesser extent. Overall, the results highlight that assumptions relating to the role of factors of production in the model have a significant effect on the economy's adjustment mechanism in response to the demand shock. The results also show that, even when the overall effect on the economy is neutral, the CGE framework can identify important sectoral implications.

Various supply-side CGE analyses also provide some insight for the subsequent applied papers in this thesis. Using the model outlined previously, Szeto (2002) also conducts a costless supply-side simulation: a permanent increase in labour productivity by means of Harrod neutral technological progress. In this simulation, higher firm productivity initially has a deflationary impact, which leads the monetary policy authority to loosen monetary policy to stimulate aggregate demand. In response, firms increase capital stock, as higher productivity raises the marginal return on capital. In time, households benefit from higher labour productivity via higher wages, which eventually increases consumption to a new, higher level. Again, in this example, monetary policy acts as an adjustment factor. In the AMOS simulations, where higher labour productivity also leads to an initial deflationary impact, monetary policy is essentially passive, and the adjustment towards a new equilibrium is not markedly different from this process. In the analysis of Chapter 4 where I use the AMOSRUK model variant, I find that changes to the external competitiveness of the economy, and the consequential impact on external trade, play an important role in stabilising the economy.

Dixon and Rimmer (2003) and (2007) use the Australian MONASH model to conduct 'what if' policy analyses relating to supply-side issues, incorporating macro forecasts into both the base case and the policy forecast, as in the previously described MONASH paper. In both Dixon and Rimmer (2003) and (2007), the MONASH model configuration is as outlined above, and the authors assume that short-run real wages are sticky, whilst long-run real wages are flexible. The effective labour supply is exogenously specified, to reflect the policy effects, and wage rates adjust over time to ensure that employment absorbs the labour supply in the long-run.

Dixon and Rimmer (2003) consider the economic implications of a government policy designed to increase the educational attainment of early school leavers. In doing so, they impose four simultaneous exogenous changes to reflect the shock: (i) a Harrod-neutral labour productivity shock, (of the kind considered in Chapter 3 of this thesis) in order to represent the benefits of reductions in crime and other social improvements associated with the policy as a reduction in the labour input required to produce a given level of output; (ii) an increase in public expenditure to reflect the costs of the policy, which is paid for via tax increases; and (iii) changes in the effective supply of labour to reflect the increased workforce participation and effectiveness of high school graduates. The authors find that in the long-run, GDP rises in response to the increased efficiency and participation of the students themselves, as well as to the general increase in workforce productivity due to the social benefits associated with the policy, and that this is associated with a fall in the natural rate of unemployment. In the short-run, however, the effects of the policy are quite different. Initially, GDP falls, reflecting the withdrawal of labour associated with increased educational participation. In addition, in the early years of the policy, there are significant tax increases to fund the policy. This leads to a short-run increase in real before tax wages, causing a reduction in employment, rates of return on capital and, by consequence, investment. Over time, wages adjust, the capital stock recovers and the effective labour supply increases, moving the economy towards a new, long-run, equilibrium. However, significant benefits of the policy change are slow to materialise – the negative consequences of the policy persist for around thirteen years after the introduction of the measures.

Dixon and Rimmer (2007) impose a similar supply-side policy shock, related to increasing the financial literacy rates of households in the lowest-financial literacy decile, and consider the economy-wide effects. The authors impose a number of simultaneous exogenous changes in the model: (i) an increase in Harrod-neutral productivity, to reflect improved decision-making in the workplace; (ii) an increase in capital formation, to reflect more home purchases and new business start-ups; (iii) increased savings and more sensible financial investment decisions; and (iv) a small reduction in the NAIRU to represent that people in the lowest decile of financial literacy are able to search and compete more effectively for jobs. In this case, the authors impose a 'costless' policy and, once again, they consider deviations against a base case forecast for the economy. As expected, there are long-run positive GDP effects associated with the increase in efficiency, and consumption, income and employment all rise, and this increase in activity is associated with an increase in imports. In this particular application of the model the balance of trade must be compatible with the income identity Y= C+G+I+X-M. Therefore, to achieve a compatible balance of trade deficit, exports also increase relative to base, and this is facilitated by an exchange rate depreciation[19]. In the short-run, however, the effects of the policy are quite different to that of the previous study. The productivity-enhancing shock means that more people can be employed at any given real wage rate, and since real wages are slow to adjust, there is a significant increase in short-run employment, which overshoots its long-run level. In addition, there are marked tax cuts, because short-run employment increases considerably in response to government expenditure. In the long-run, wage rates adjust and the economy moves to a new long-run equilibrium that is characterised by higher consumption, employment, investment and GDP.

These papers therefore highlight the usefulness of CGE modelling for analysing policy changes. In particular, they demonstrate the importance of obtaining period-by-period results of the adjustment process of the economy following an exogenous shock. In Dixon and Rimmer (2003, 2007), each policy shock results in maximum benefits only in the very long-run, and the short-run effects can differ quite markedly. Such issues can be crucial for appropriate policy-making. In the subsequent applied analyses in this thesis, where period-by-period results are also considered, I too find that the aggregate

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[19] This is in contrast to the configuration of the AMOSRUK and UKENVI CGE models used in this thesis, where the exchange rate is not actively managed so as to maintain a specified balance of trade deficit.

impacts differ over the short and long-run adjustment periods. In addition, the MONASH studies identify the importance of the researcher's modelling approach, since similar policies conducted within even slightly different frameworks and/or different assumptions lead to very different simulation results.

4.2 Interregional CGE analysis

4.2.1 Top-down versus bottom-up models

The development of interregional CGE models has been slower than that of national models, most likely due to the data constraints involved in model specification. Nevertheless, there are a number of operational interregional models in the literature and, as for the literature on national CGE modelling, the studies differ widely in terms of model structure, type of application, country of origin and so forth. A large proportion of interregional CGE models relate to the Australian and the US economies, and they are most commonly used for analysis of price-based policies, such as taxes and subsidies. In this chapter, I consider the characteristics of some prominent models and their wide-ranging applications in the literature, before focusing on the differences in theoretical specification, interregional linkages and closure rules amongst key CGE models.

Examples of some early interregional CGE models include the multi-regional variant of the ORANI model (Dixon et al., 1982). This model provides a top-down approach in addressing regional issues, rather than the bottom-up approach used in AMOSRUK. As outlined earlier, the top-down approach involves disaggregating national results to a regional dimension on an ad hoc basis, and for the interregional ORANI model (Dixon et al., 1982), the approach involves: (i) producing national aggregate simulation results for a particular policy question; (ii) allocating the national aggregate outputs amongst the regions via constant-regional-share assumptions[20]; and (iii) imposing the condition that demand for local regional goods equates with the supply of local regional goods. Other similar top-down interregional models include Horridge et al. (1995), and more recently Parmenter and Welsh (2000) combined a top-down regional equation system with the MONASH dynamic model of Australia (Dixon et al., 2000) to produce the MONASH-RES model for use in regional forecasting and policy analysis[21]. In these models the behaviour of economic agents at the regional level is not explicitly modelled, nor are there active regional feedback effects. This makes the model specification process much less data intensive than that of the AMOSRUK model, since interregional trade flow data, for example, are not required. However, the top-down modelling approach means that the impact of policies which originate in the region(s) cannot be considered.

Hybrid approaches are developed in Higgs et al. (1988) and Liew (1995): both of these models are essentially top down, but incorporate some limited elements of the bottom-up approach which allows for more explicit specification of the regional economies. Higgs et al. (1988) present a top-down equation system that incorporates a partially regionalised CGE model. The national data set is sectorally disaggregated such that regional sectors are explicitly specified. This allows for analysis of some regional shocks, but the absence of feedback effects between the regions rules out analysis of region-wide shocks. Liew (1995) does incorporate some feedback effects between the regions, but the source of the interaction is limited to only one component of final demand.

In the research conducted in this thesis, the analysis is concerned with the impact of regional policies (for Chapters 3, 4 and 5), and therefore a bottom-up model is the most appropriate modelling methodology, since this allows for endogenised interactions

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[20] An adaptation of the method proposed by Leontief et al. (1965) for regional disaggregation of national I-O outcomes is used.

[21] More recent interregional versions of the MONASH model adopt a bottom-up specification (Gieseike and Madden, 2006). These are discussed later in this chapter.

amongst the regions via interregional linkages which are crucial to the outcome of the policy-related shocks. The results of Liew (1984), however, suggest that the introduction of interregional commodity flows has a limited effect on results. He compares the results of a trade policy shock in the ORANI top-down model with an extension of ORANI that is constructed adopting a bottom up approach. This finding, however, holds only under very restrictive assumptions, including constant technology and sales patterns among regions and uniform price and expenditure elasticities for each commodity across regions. Furthermore, there are crucial differences in the results for the individual regional industries – an important consideration in regional policy analyses. McGregor et al. (1996a) compare the results of the single region AMOS model for the Scottish economy with the interregional AMOSRUK version, where interregional behaviour is explicitly modelled, and find that exogeneity assumptions regarding regional prices and quantities can generate significant long-run bias in the results for regional variables. Parmenter et al. (1985) compares the simulation results of a national policy shock using three basic CGE frameworks which are constructed according to the bottom-up, top-down and hybrid approaches. The author uses a specially constructed illustrative database to minimise data bias, and he too finds significant differences in the results for each of the model types. For the research in this thesis, the existence of purpose-built interregional I-O tables for the UK allows for reliable model specification at the regional level[22], and this facilitates use of a bottom-up interregional CGE framework. The remainder of this literature survey concentrates on the use of this type of interregional model.

Bottom-up interregional CGE applications include the analysis by Jones and Whalley (1988, 1989), who develop an interregional CGE model for Canada and use the framework to assess the regional implications of various government policies, mostly relating to taxation. Morgan et al. (1989) considers the long-run impact of tax initiatives on regional production patterns, and Hirte (1998) assesses the welfare implications of

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[22] However, the absence of official up-to-date and consistent I-O tables presents various research constraints. This issue is discussed further in Chapter 7.

regional income tax policies in Germany. Other studies relate to the evaluation of government investment policies. Gunn (2004) evaluates the use of a regional CGE model for the UK for the evaluation of transport investments in the UK, and Miyagi et al. (1998) uses a nine-region CGE model to measure the multiregional impacts of transport policies in Japan. Gieseike and Madden (2006) use the bottom-up interregional variant of the MONASH model, MONASH-MRF, (Naqvi and Peter, 1996), to model the demand and supply-side stimuli associated with university activity in the Australian region of Victoria. Other interregional extensions of the MONASH model for Australia include MMRF-Green, which is suitable for environmental analysis. Adams et al. (2000) use it to analyse the regional implications of a variety of pollution-trading schemes that are designed to limit emissions.

The impact of structural changes and macroeconomic shocks are modelled by Kraybill et al. (1992) for the US economy and Haddad (1999) for the Brazilian economy. Kraybill et al. (1992) use an interregional CGE model for the US economy to demonstrate that apparently aspatial macroeconomic policies applied at the national level can alter the geographical distribution of national output and income, whilst Haddad (1999) considers the implications of various economic development policies on regional inequalities. Gazel (1994) analyses the impact of the Free Trade Agreement between Canada and the US using a multi country CGE model that incorporates trading blocks for the US, Canada and the rest of the world, and where the US economy is disaggregated into four regions. The study shows that the gains from trade are disproportionately concentrated across the regions. Haddad and Hewings (1999) use the B-MARIA model of Brazil to study short-run regional effects of new investments and technological upgrade in the Brazilian automobile industry.

4.2.2 Theoretical specification

Many bottom-up interregional CGE models share common features in terms of their theoretical specification, with the structure of household demand and production technology determining the demand and supply relations in the model, and functional forms generally based on multilevel structures that allow for a number of substitution possibilities. Two broad categories of production inputs are incorporated: primary factors and intermediate inputs, with studies specifying the exact nature of these according to the application. Whilst the AMOSRUK studies recognise labour and capital as primary inputs, other studies incorporate land as a factor of production, where appropriate for the analysis. Kilkenny (1993), for example, includes land in her study of the interregional impacts of the termination of farm subsidies in the US. The use of standard functional forms such as CES, Cobb-Douglas or Leontief specifications (and linear expenditure system preference functions for the households sector) is widespread, owing to their attractive structural properties (see Dixon et al., 1982) and their relatively low requirements for parameter determination (Koh et al., 1993). Data limitations have generally prevented more flexible functional forms being estimated for interregional models, though there are exceptions. Despotakis and Fisher (1988) adopt a generalized Leontief specification in their model for California, whilst Dixon et al. (1982) suggest the use of constant ratios of elasticities of substitution, homothetic (CRESH) functions. These are a generalisation of CES which allow for the elasticities of substitution between different pairs of inputs to differ. In Dixon et al. (1982), however, concerns regarding the appropriateness of the estimation method meant that the authors instead reverted to the use of CES functions.

4.2.3 Interregional linkages and closure rules

Interregional linkages in a CGE model typically arise via trade commodity flows as well as via factor mobility of capital and labour. The nature and extent of such interregional feedback effects has been shown to have a significant effect on results (see Section 4.2.1 above). In a series of simulations using an interregional CGE model for Indonesia, which incorporates interregional trade and factor mobility, Watanuki (1996) shows that new investments in less developed regions lead to relatively greater benefits for more developed regions via interregional feedback effects. Hulu and Hewings (1993) also find that the more dominant region benefits relatively more, in terms of the effects on total output, from an equal increase in exports by each sector across all regions, and that this is due to the structure and extent of the interregional linkages amongst the regions. They use an I-O rather than a CGE model of the Indonesian economy in the study, however, and exclude the evaluation of employment, income and income distribution effects.

Factor mobility also has an important role in depicting interregional linkages. Interregional, intersectoral and/or international factor mobility may be incorporated. Capital is generally assumed to be immobile in the short-run, and those studies that allow for long-run capital mobility tend to motivate long-run capital movements via differences in rates of return or productivity amongst regions and sectors. Labour mobility is commonly stimulated by regional wage differentials. Harrigan and McGregor (1988) demonstrate that differences in the configuration of the UK labour market relating to the mobility of labour (as well as wage determination) can have an important impact on simulation results, using the interregional version of AMOSRUK. Morgan et al. (1989) incorporate varying degrees of labour mobility, from perfect mobility through to immobility, and also find that the extent of labour mobility has a significant impact on regional growth, because constraints on the supply of labour mean that less capital is drawn to the region.

Mechanisms other than wage differentials have also been used to motivate interregional labour mobility. In Ko (1985) and Ko and Hewings (1986), labour mobility depends on wage differences across sectors and regions, as well as differentials in expected wages over some horizon plan, in the spirit of the Harris-Todaro (1970) hypothesis. Jones and Whalley (1988, 1989) assume partially mobile labour among regions by establishing that individuals' migration decision is based on a trade-off between income differentials amongst regions and their locational preference. Thus they assume that individuals in each region hold different degrees of locational preference, and the authors specify individuals' utility function in a region as being the maximisation of two sub-utility functions; each of which represent the utility derived from consuming the same basket of goods inside and outside the region. Gazel (1994) incorporates the utility-equalisation across space theory used in urban economics, whereby labour migration depends on wage and price differentials, up to a limit when utility is equalized in all regions.

The closure specified for the model heavily reflects the theoretical or policy application of the model and, for interregional models, plays a role in determining the nature of the interlinkages between the individual regions. In the simulations in this paper, I concentrate on a range of labour market specifications which represent alternative visions of the regional macro-economy. These labour market closures reflect different assumptions about wage determination and population constraints. By changing these assumptions, the nature, direction and extent of regional interactions are affected.

In Peter et al. (1996), for example, the authors consider the determination of regional investment via alternative closures within the multi-regional MONASH-MRF model: comparative statics and forecasts. In the former, capital stocks in regional sectors are exogenously specified. Aggregate investment is also determined exogenously, and is allocated across the regional sectors according to relative rates of return. This configuration is used to show the effects of one or a few exogenous changes to variables of interest. For the forecasting simulations, the demand for investment in each regional sector is described by an estimated forecast growth rate for the industry capital stock and an accumulation relation which links the capital stock and investment rate of the forecast year to that of the following year/period. In contrast to the comparative static set-up, the forecast specification also incorporates changes in all exogenous variables that are assumed to occur during the simulation period. This requires that estimates are drawn from other sources, such as government or private sector macro forecasts.

4.2.4 Calibration

Shoven and Whalley (1992), Koh et al. (1993) and Partridge and Rickman (1998) consider the calibration method employed in CGE models. The availability and reliability of regional data presents various data related problems for interregional CGE models. Often, interregional commodity flows data are not available, and many authors use non-survey techniques to estimate these variables, which can lead to bias in the estimates. Techniques for estimation include gravity-type models (Leontief and Strout, 1963; Gibson et al., 2004), the contingency table method (Batten, 1982), and an amalgamation of Round's method (Round, 1978, 1983) with improvised separations of the rows and columns of national I-O tables on the basis of extraneous regional shares (Hulu and Hewings, 1993). In the MONASH-MRF model, which is a bottom-up model in the sense that behavioural relationships are specified at the regional level, the construction of the interregional I-O table involves spatial disaggregation of the national table via ad hoc splits of rows and columns based on regional shares. Haddad and Hewings (2003) argues that this could compromise the modelling process, and that the techniques of Round (1978, 1983) or Hulu and Hewings (1993) are more theoretically sound. Using Hulu and Hewing's (1993) hybrid procedure, Gazel (1994) estimates interregional trade data, and carries out sensitivity analysis for the interregional commodity flows data. A 10% increase in imports was found to have no impact for aggregate income results, though there were substantial differences for capital and labour incomes. Moreover, even where fully specified interregional I-O tables are available, there may be issues regarding the construction method. Israilevich et al. (1996) reveals that differently constructed I-O tables would have a significant effect on the results of a regional econometric model, both in forecast and impact analyses.

5. Developments in CGE modelling

Advancements in computing software, together with the appeal of CGE modelling as a tool for policy analysis, has meant that CGE modelling has been a productive area of research in recent years. Until relatively recently, CGE models, especially regional and interregional models, tended to be comparative static in nature. However, one area of progress relates to the incorporation of dynamic properties into the model structure (Harrison et al., 2000), allowing for growth to be endogenised. In most cases, the dynamic properties are recursive in nature. This involves the linking of a sequence of single-period equilibria through stock-flow relationships. The computed equilibria vary over time as the value for the model's stock variables adjust. Flows in previous time periods (for example investment, interregional migration, and government borrowings) have an effect on values of endogenous variables computed in each period via their influence on the values for the stock variables in each period (for example capital, population and government debt). Recent examples of this type of dynamics exist in the RAEM 3.0 model (Ivanova, 2007), a CGE model for the Netherlands. This framework incorporates dynamics of capital accumulation and technological progress, stock and flow relationships and backward looking expectations. In each period, the model is solved for an equilibrium given the exogenous conditions assumed for that particular period, with the equilibria linked via capital accumulation.

In contrast, full multi-period dynamic CGE models explicitly incorporate agents' forward looking expectations, and this requires all periods to be solved simultaneously. There are few of this type of CGE framework in the literature, though Bröcker and Korzhenevych (2008) specify one such model, which endogenises the savings-investment behaviour of forward-looking agents. In this model, households are assumed to maximise their utility function over time, taking into account their intertemporal budget constraints, and that prices and interest rates vary over time. For their part, firms maximise their present values, and the existence of capital stock adjustment costs smoothes the response of capital stocks to shocks.

Dynamic specifications in interregional models have been much slower to develop. AMOSRUK incorporates recursive dynamic aspects relating to endogenous investment and interregional migration (see Chapter 3, Section 2). Similarly, in the multi-regional Australian MONASH model, recursive dynamics are incorporated as before: flows of investment, migration and/or government borrowing in preceding time periods determine the values for endogenous variables computed in each period via their contribution to the model's stock variables in each period (such as capital, population, government debt) (Dixon and Rimmer, 2002).

By endogenising potentially important sources of economic growth, these dynamic models may capture crucial aspects of a policy change or exogenous shock that a static simulation excludes, and static models may therefore over- or under-state the benefits from a policy-induced exogenous shock. Despite this particular shortcoming of comparative static models, a large number of simulations are of this kind, owing to the fact that dynamic models, being more theoretically complex, are more difficult to solve.

As an alternative, there are also a number of empirical dynamic macroeconomic models which are linked with national CGE models via variables that are endogenous in one and exogenous in the other, so that the results of the macro models are imposed on the CGE model[23]. Whilst some authors advocate the robustness of this so-called 'ecumenical' modelling strategy, others prefer a direct fusion of the two techniques, whereby a CGE model is embedded in a dynamic macro model, allowing for Walrasian CGE elements to be integrated with macro or financial models. Robinson (2003) and Robinson and Lofgren (2005) provide a discussion.

Other dynamic CGE models include the overlapping generation (OLG) type, which are based on the early developments of Auerbach and Kotlikoff (1987). In these models, there is a turnover of population: individuals live for two periods and at any point in time, there are two generations ('old' and 'young') living together. When a policy influences two generations in different ways (e.g. a tax reform that benefits one

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[23] Powell (1981) describes an early application of this approach using the ORANI model of Australia.

generation more than the other), there will likely be consequences for the aggregate savings rate, capital accumulation and economic activity. The OLG CGE model allows such important intergenerational issues to be considered. Recent applications include that of Wendner (2001), who considers the possibility of using revenues from CO_2 taxation to partially finance the pensions system, and shows that environmental policy and pension reform may be mutually compatible objectives. Although OLG CGE models have also proved useful in the analysis of other policy concerns, such as social security reform and ageing and demographic issues, in practice, an OLG CGE framework with multiple regions and sectors still presents a considerable computational difficulties, and requires several trade-offs with the level of detail that can be captured by the model.

The parameterisation of CGE models continues to be a contentious issue, and a number of authors have contributed to advancements in this area. Partridge and Rickman (1998) suggest practical solutions that lie somewhere in-between model calibration and full econometric estimation of CGE models. For example they highlight that Adams and Higgs (1990) compute averages of a number of years of data for a key sector due to concerns that the benchmark data set may not be representative of the underlying economic structure. Other approaches include that of Adkins et al. (2003), who use a Bayesian approach to estimate production function parameters in a regional CGE model of Oklahoma, where regional data was limited and of poor quality. The Bayesian approach involves taking into account prior information about likely values of the elasticities or other parameters. Since the abundance and quality of data is greater at a national than a regional level, estimates based on these can be a good source of prior information for Bayesian estimation at the regional level. Alternatively, in a CGE model of Mozambique, Arndt et al. (2002) use a maximum entropy approach to calibrate the model, and use the framework to explain Mozambique's recent history.

Other recent CGE models explicitly incorporate imperfect competition. Since the seminal work of Harris (1984), which incorporates imperfect market features such as market power and price setting, there have been a range of modifications made to the standard CGE model in order to introduce imperfectly competitive elements. Many approaches assume that products are heterogeneous across firms and countries/regions, and that firms possess a degree of market power, though there are key differences in assumptions regarding price discrimination, product differentiation, strategic behavior, expectations and market entry. Extra data are required to calibrate the model and, where these data are not completely available, as is often the case, additional ad hoc assumptions may be imposed. These technical choices in the design of the model structure may have an important impact on model results, and may increase uncertainty regarding model outputs. Roson (2006) compares results from the same simulation exercise, which is performed for alternative model configurations: one standard competitive and three distinct imperfectly competitive model formulations. He finds that the imposition of imperfectly competitive elements does affect the simulations results. In particular, the alternative configurations of imperfect competition result in quite different findings and implications.

6. Strengths and Weaknesses of the CGE methodology for policy evaluation

In this section, I evaluate the main strengths and weaknesses of CGE modelling for the purposes of national and regional policy analysis, and comment on possible approaches to overcoming key weaknesses in the use of CGE modelling in practice. I also provide an overview of alternative modelling methodologies and identify their main advantages and drawbacks relative to the CGE approach.

6.1 Strengths of CGE modelling

A key strength of the CGE modelling approach relates to its microfoundations. In CGE models, the optimizing assumptions associated with general equilibrium modelling are typically preserved, which therefore allows for an analysis of the effects of a policy or exogenous change at the micro level. The method involves explicitly modelling the behaviour of producers and consumers, so that behavioral assumptions are clearly stated, and this formal structure aids in the comprehension and transparency of the model. Despite the incorporation of these complex microfounded relationships, CGE models are still able to produce a numerically precise equilibrium solution to the model simulations. Alongside the benefits of having credible theoretical underpinnings, the model structure allows that alternative model specifications can be compared and contrasted, allowing for a full examination of the effects of different functional forms on the model simulation results (Cox and Harris, 1985; Greenaway et al., 1993).

The ability to incorporate interdependencies and feedback effects is another important feature of the CGE modelling approach. The regional impact of changes in policies or exogenous shocks may be significantly different from the aggregate effects (Nijkamp et al., 1986, pp.259 and 261; Miller and Blair, 1985, p.63). Furthermore, most policy changes are likely to have impacts beyond only the target variable or sector. Such economy-wide, spatially-disaggregated effects are difficult to capture in anything other than a general equilibrium framework. The complexity and multitude of the interlinkages mean that an assessment of a policy shock or reform could not be carried out analytically in sufficient detail. Only computer based-simulations allow for all the interactions to be incorporated and tracked. A CGE model therefore offers significant value in understanding these complex interactions in the economy.

The degree of aggregation of the model will be dependent upon the policy question at hand, but a further useful aspect of the CGE framework is that, should a sector or subsector be of particular interest, it is relatively straightforward to disaggregate the data set upon which the model is based[24]. This means that the analyst can identify and compute the gains and losses of the policy at the sub-sectoral (or sub-regional) level for the sector (or region) of interest. In addition, not only can the model identify the sources of income gains or losses from the policy reform, but it can also show how these effects

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[24] However, this is subject to data availability and, in the case of interregional models in particular, a degree of aggregation is often required in order to ensure data consistency.

are distributed among sectors or regions (or groups of society or social class of household, depending on the data used to specify the model). Since all policy effects will have distributional consequences across the economy - whether sectoral, spatial or welfare-related – this feature helps inform policy assessment[25].

The flexibility inherent in a CGE framework makes it particularly useful for evaluating the response of the economy to a range of policy shocks. Alternative types of model simulations can be carried out within a common framework using the same benchmark data set. Re-estimation of the framework is not required for each simulation, which aids the process of comparison, and the alternative deviations from that equilibrium can be considered for a range of exogenous shocks. Multiple simulations can be undertaken, for example, to work out alternative policy changes that might turn a national income or loss into a gain, and the policy shocks can be either marginal or non-marginal in nature. The effects of policy 'packages', where there is a change to more than one exogenous variable, can also be considered and compared. Alternatively, where there is uncertainty surrounding some aspect of the economy, such as the true characteristics of the operation of regional labour markets, for example, various configurations can be incorporated into the framework, and the consequences for model results can be analysed. Similarly, alternative parameter values can be incorporated into model simulations in order to check for robustness of results. The existence of a common framework within which alternative model simulations are conducted means that each set of results can be numerically ranked in term of the impact on prices, income, welfare or distributional grounds, according to the specific policy issue.

An additional attribute of the CGE approach to modelling is that it disciplines thinking about the structure and operation of actual economies, which is a crucial prerequisite for sound policy-making. CGE models can validate or refute policy-makers' presentiments

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[25] This thesis does not consider the welfare effects of the simulated exogenous shocks, but in principle the CGE construct can model welfare changes explicitly through the use of measures such as compensating variation and equivalent variation, so as to consider the net welfare benefits of alternative policy reforms within a framework with solid theoretical foundations.

about the likely effects of a policy, and can emphasise unanticipated outcomes. They help to demonstrate the means via which a policy works its way through the economy and, for the case of period-by-period analyses, explicitly describe the adjustment process of the economy. As they do so, the model results can highlight any anomalies in the short-run versus the long-run effects. Further, they encourage a more inclusive approach to policy analysis by helping to develop a wider perspective about the impacts of a policy or exogenous shock.

CGE modelling also lends itself particularly well to informing policy formulation at the regional level. Regional time series data sets are often inconsistent or insufficient in terms of the number of observations for regional econometric modelling approaches, which often come up against significant constraints in their specification and implementation. As a result, assessment of regional policy has often involved the use of purely demand-side models based on I-O frameworks (Armstrong and Taylor, 2000, p.35). Although the data requirements of such methods are relatively low, there are significant limitations to the approach (see Section 7.3). CGE models, on the other hand, are able to overcome some of these limitations without the requirements of rich data sets (although there are issues relating to the reliance on secondary sources for the parameterisation of key model variables, and the timeliness and consistency of official I-O tables[26]).

6.2 Weaknesses of CGE modelling

As with all techniques in applied economics, there are limitations associated with the CGE methodology, though modellers can adopt a number of approaches that attempt to minimise these.

Although, theoretically, a CGE model can accommodate any functional form, modellers typically use only ‘well-behaved’ functional forms that are relatively straightforward

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[26] Chapter 7 discusses these issues further.

and tractable to use. This often means CES or Cobb-Douglas forms, for example, being specified in the model. Whilst there is a significant volume of literature to suggest that CES functional forms fit production and consumption data relatively well and perform well in such econometric studies (see Arrow et al., 1961; McFadden, 1963; Uzawa, 1962), in practice, agents' behaviour may not actually be consistent with these. Furthermore, the results of a number of studies stress that CGE model predictions may be sensitive to the use of the CES class of functions versus, for example, flexible functional forms (Hertel, 1985; McKitrick, 1998).

Similarly, modellers face various constraints relating to the numerical specification of the model. The model is calibrated to a benchmark year, which is assumed to be an equilibrium, and the calibration practice is justified on the grounds that the values which result from the calibration process are consistent with the equilibrium. However, the assumption of an equilibrium may not necessarily hold in practice (see further discussion later in this section), and there are no procedures for checking the validity of the calibrated values. Furthermore, this benchmark data set is often aggregated to a degree that can obscure important underlying relationships, and this aggregation may be necessary for interregional CGE analyses in particular, where national or regional I-O tables need to be aggregated to ensure consistency. An additional important criticism of the CGE approach is the quality of the information used to derive the parameters which are not specified using the SAM data or via calibration. For example, Hertel et al. (2004) accept that the history of estimating the substitution elasticities governing trade flows in CGE models has been "checkered" at best. In many cases, CGE model builders do not statistically estimate these parameters themselves, but use estimates from secondary sources, and these often do not relate to the same time period or geographical location of the analysis. The substitution and Armington elasticities of the GTAP multi-country CGE modelling framework (Hertel, 1999b; Dimaranan et al., 1999), for example, are taken from the SALTER project (Jomini et al., 1991), and are mapped to the appropriate GTAP sectoral classification. The income elasticities are taken from the Food and Agriculture Organisation's (FAO) World Food Model (FAO, 1993), which itself uses some variable estimates drawn from secondary sources (Theil et al., 1989). The secondary data estimates often relate to different country and/or commodity coverage than that of the original model (e.g. Hertel, 1999b).

In the Michigan model (Brown et al., 1992), a multi-country CGE framework also used for trade analysis, the elasticities are also estimated from a different data set (Deardorff and Stern, 1990). Moreover, there is no capacity for formally testing the appropriateness of functional forms, parameter values or model structures. Unlike for macroeconometric models or partial equilibrium econometrically estimated models, there is no means of applying diagnostic tests, comparing actual versus fitted values, or measuring the degree of confidence that the user can have in the model results. However, formal sensitivity analysis can be used to examine the robustness of CGE model results, and focused sensitivity analysis for parameter values and behavioural functions is a useful means of testing the significance of particular assumptions in influencing model outcomes.

The existence of data constraints often necessitates the use of secondary data sources for parameter values. However, one way of alleviating this criticism would be for the modeler to provide additional information in the form of, for example, standard errors, functional form, and so forth relating to the estimates, since this could provide some information about the reliability of such estimates. In practice, space constraints in academic articles often prohibit such practice, though references are often (but not always) provided. Systematic validation of CGE simulations, through sensitivity analyses of the parameter values and/or model specification, as well as ex post validations of the results, is therefore beneficial for supporting the credibility of model results.

The perceived uniqueness of particular solution values is also a potential weakness of CGE analysis. The modeling approach assumes a unique equilibrium exists, and results are computed on this basis. In practice, however, multiple equilibria are possible. The use of the ‘well-behaved’ functional forms of, for example, the CES type makes this an unlikely prospect, however. There are no known cases of multiple equilibria, and the convention in the literature is to assume that a unique equilibrium exists unless shown otherwise (Greenaway et al., 1993).

A further weakness is related to the specification of the model structure: specifically to the difficulty involved in incorporating important economic phenomena into the model framework. In particular, the incorporation of intertemporal flows, expectations, growth processes in general, monetary sectors and monetary flows is not straightforward in CGE modelling. As outlined in Section 5, many modellers do incorporate such characteristics, though the handling of these issues is often simplistic.

Although other modelling methods, such as dynamic stochastic general equilibrium (DSGE) or macroeconometric models, are more advanced in their treatment of dynamics, this feature can create its own modelling constraints relative to the CGE approach. The added complexity of a dynamic model framework, for example, can render the modelling method more assumption driven, and less tractable that static models, and the increased data requirements can make this a difficult (and in some cases possibly unnecessary) approach for many policy analyses[27]. On the other hand, simple, static simulations are likely to miss crucial parts of the story. In some regards, since information about an economy and the way that it will react to changes are never perfect, the modeler may be able to lessen reservations about precise model results and reduce the possibility of reliance on spurious results by obtaining a range of possible estimates based on alternative parameter assumptions and model specifications, and including intertemporal variants where feasible.

Overall, although CGE techniques provide invaluable guidance for policy-making and enable analysts to consider the consequence of major policy changes, the simplifying assumptions that are often necessarily imposed, together with various data constraints,

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[27] Though intertemporal calibrated CGE models do exist - Lecca et al. (2009) presents such a model for the region of Sardinia.

mean that the outcomes of CGE models must often be interpreted as ‘insights’ rather than absolute truths. Criticisms have been made of CGE applications when the authors assert a degree of precision over the results, which perhaps cannot be justified by the quality of information that is inputted to the model, or the extent of sensitivity of the results to assumptions.

In the presence of these constraints, there are a number of ways to encourage greater confidence in the simulation results. These include sensitivity analysis: changing the model parameters or model specification in order to determine the effect on the simulation results. In the case of parameter sensitivity analysis, Piermartini and Teh (2005) suggest that if a subset of parameters of the model has been estimated econometrically, then information on the standard errors of the estimated parameters can be used to inform the sensitivity analysis[28].

Furthermore, Kehoe (2003) has suggested the practice of systematic ex post evaluations of CGE simulations. This involves the CGE modeller comparing the results of the CGE model with actual data, in order to see if the results can be validated by outcomes, or whether comparisons with actual data throw up surprises that warrant further investigation. Kehoe (2003) follows this process to consider the performance of CGE predictions of the impact of NAFTA. This type of ex post evaluation is routine for macroeconometric forecasting models. While there may be a need for conducting more ex post validation of CGE models and simulations, it should be noted that this is not a trivial task. In a standard comparative static analysis for a model calibrated for, say the year 2000, the model is shocked by changing one or more exogenous variables, such as imposing a domestic demand shock, and the results of the simulation are compared with the base year for 2000. An ex post validation of the simulation would involve comparing these results with actual data in, say, 2005. However, for the sake of consistency in comparison, the process would involve removing all extraneous effects

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[28] That is to say, the parameter values could be drawn ‘randomly’ from a population that has the same probability distribution as those from the econometric estimation (Piermartini and Teh, 2005, p.20).

that occurred in the intervening years, such as the impact of significant regional, national or global economic events.

Perhaps the most often stated criticism of CGE modelling is the so called 'black box' nature of the simulations. This refers to the conjecture that the causality between assumptions underlying a CGE and the results produced often remain impossible to decipher, due to the complexities of the relationships that are modelled (Hertel, 1999a). This therefore lessens confidence in the results and the robustness of the outputs. However, a number of modelling routines can address this issue. Extensive sensitivity analysis and an incremental approach to model augmentation can help to reveal the exact causalities underlying the adjustment process that follows from an exogenous shock. Furthermore, the transparency of CGE model structures and closures, together with a flexible model framework which allows the modeller to track the source of any surprising results, also aids the clarity of interpretation of the results.

7. The value-added of CGE modelling relative to other modelling approaches

Several methodologies exist for evaluating the economic consequences of exogenous shocks at a national and/or interregional level. Certainly, there is no faultless methodology for policy analysis. Since all economic models are, by definition, an abstraction of reality, simplifications of and generalizations about the real world are inevitable within each structure. The type of issue to be addressed is critical in influencing the most appropriate modeling approach. In this section, I evaluate the suitability of a wide range of models for analysing policy issues or exogenous shocks. I do not attempt an assessment of the overall aptness of the method – instead, I compare their key advantages and disadvantages vis-à-vis CGE modelling for the specific purpose of conducting ex ante policy-related analyses at the national and/or regional level, and where observed data may be scarce. I focus only on a selection of modelling approaches that could feasibly be used for this purpose.

7.1 Partial equilibrium modelling

Partial equilibrium analyses typically focus on the economic outcomes of an effect in one market of the economy, without considering the impact in other markets. An implicit assumption is that feedback effects between markets are of second order significance: the impact of the sector in question on the rest of the economy is assumed to be either small or non-existent. Linkages and interactions between this sector and the rest of the economy, for example through factor incomes and expenditures, are therefore ignored. This means that partial equilibrium modelling cannot take into account the economy-wide resource implications of an exogenous shock: for example the situation where, to increase production in one sector or region, resources may need to be displaced from other sectors or regions. Thus modelling the impact of regional or sectoral spillovers, income effects, the substitutability and complementarity of products, or shifts in the factors of production among sectors and so forth within a partial equilibrium framework would necessarily be restrictive and simplified. By its very nature, partial equilibrium analysis must exclude those interdependencies which are central to general equilibrium analysis, and which are of interest in the policy evaluations carried out in this thesis.

A partial equilibrium model is therefore most suited to policy analysis related to sectoral issues, or when the sector or region in question corresponds to only a small share of total economic income, or where the exogenous change is likely to affect price in only one sector or region, leaving prices in other markets constant (for example, when either the demand and supply functions are perfectly elastic). Further, they can be useful where a rich data set exists, allowing for a ‘sharp-focused’ answer, or for a ‘one-off’ policy issue, given the high set-up costs of a CGE model. In contrast, CGE modelling can be more appropriate for longer run, broad-based policy issues where a whole-economy analysis is required. However, the economy-wide nature of CGE analysis means that this approach may be more complex and data-intensive than comparable partial equilibrium analyses. Furthermore, a relatively higher level of data aggregation may be required for a CGE model compared to a partial equilibrium one, in order to ensure consistency across a whole-economy data set such as a SAM (particularly for interregional data sets)

7.2 Spatial econometric models

Spatial econometrics, a methodology for the econometric analysis of data observed across space, has been used extensively in regional economic analysis (Fingleton, 2001). In contrast to traditional econometric techniques, they are able to incorporate notions of spatial dependence and spatial heterogeneity - critical aspects of the data used in regional analyses - in contrast to traditional econometric estimation techniques, which become inappropriate in the presence of such characteristics. The common approach in spatial econometrics involves analysis of a space-time data set (distinct from that of a panel data set) in order to explore the spatial characteristics of the data, accompanied by spatial regression modelling and tailored misspecification tests. Although these models embrace notions of spatial interactions and spatial spillovers, of the type that are crucial to some of the analyses carried out in this thesis, and, increasingly, are theoretical rather than data-driven (Fingleton, 2007), they also tend to be partial equilibrium in nature, and data restrictions constrain the level of sectoral detail incorporated, since the models are specified using time-series cross-section data sets. Furthermore, they lack the inherent flexibility of CGE models which allow policy alternatives and a range of model specifications to be compared without re-specification of the fundamental model. However, spatial econometric models do have better recourse to diagnostic testing. As such, the models are used for a wide range of ex post studies on, for example, population-employment dynamics across space, regional convergence of income and spatial income inequalities. These issues are extremely relevant for informing policy analysis in general, but not for specific, ‘what-if’ analyses of the type this research is concerned with.

7.3 Fix-price models

Fix-price models such as I-O and SAM models benefit from a rich specification of the production sectors of an economy. They implement an economy-wide approach to modelling and are able to depict inter-industry and/or interregional relationships within a national framework. Given a fixed technological structure, I-O models estimate the direct and indirect effects of a change in, for example, final demands, upon variables such as production, value added and employment across all sectors and/or regions simultaneously. One major shortcoming of the method, however, is that a conventional demand driven I-O model assumes an entirely passive supply-side in the economy, such that supply is assumed to be infinitely elastic in response to changes in final demand. Therefore supply-side effects such as cost and capacity variations cannot be modelled appropriately. The exclusion of supply-side restrictions on economic expansion, however, has tended to result in over-optimistic presumptions about the outcome of policies such as regional selective assistance (Gillespie et al., 2001a). Although it is possible to construct a supply-driven I-O model, this method too has been subject to criticism (e.g. Oosterhaven 1988, 1989) and, furthermore, it is still not possible to model both supply and demand (or prices and quantities) simultaneously. In contrast, CGE models allow for the incorporation of both demand- and supply-side effects, which has meant that regional policy modelling has begun to shift in favour of a CGE approach.

An I-O framework is further restricted by the assumption of universal Leontief (fixed proportions) technology, such that inputs always enter in fixed proportions to produce a unit of output and there is zero elasticity of factor substitution. Therefore, the input that poses a binding constraint determines the amount of output to be produced. Furthermore, I-O and SAM models do not have the inherent versatility of a CGE model framework such as AMOS and its variants, where the impacts of a range of model closures can be considered within a common framework, and the results compared and contrasted. Indeed, CGE frameworks can be specified such that they effectively represent a fixed price model as a special case, should circumstances dictate that this is appropriate. In Chapter 5, I explicitly demonstrate that the more flexible CGE approach, which models behavioural relationships in a more realistic and theory-consistent manner, is more appropriate and informative for the type of policy analyses conducted in this thesis.

7.4 Macroeconometric, dynamic optimization and optimal control models

In some regards, CGE modelling can be seen as complementary to macroeconometric, or dynamic optimization/optimal control models, in the sense that some of the weaknesses of the CGE approach are the strengths of these other approaches, and vice versa.

Macroeconometric models are able to explain the impact of a change in economic policy on aggregate variables in an economy over time. They have a firm basis in economic theory, and, unlike many CGE models, they are typically adept at incorporating detailed dynamic characteristics of the economy such as expectations, growth, capital accumulation and resource depletion. In addition, they are able to embrace notions of market disequilibrium, and monetary variables, for which CGE models are also typically less advanced in their treatment[29]. Furthermore, the parameterization methods of macroeconometric models are superior to those of CGE models, since the modeler can use time series data and well-understood estimation techniques. This is in comparison to the reliance on calibration, and exogenous determination for many key parameters within a CGE model. Significantly, the econometric estimation of the models means that there are the associated benefits of diagnostic testing in the form of calculation of standard errors, confidence intervals and so forth, which is also lacking in the CGE approach.

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[29] Though attempts have been made to include: monetary variables, dynamic characteristics and imperfect competition in CGE models (see Section 4.3).

Nevertheless, macroeconometric models often have insufficient detail of the microeconomic structure of the economy. The production, investment and consumption functions that macroeconometric models are based on may not be a satisfactory reflection of the microeconomic structure of the economy. Furthermore, macroeconometric models tend to be lacking in their ability to provide sufficient detail on the distributional and efficiency effects of exogenous changes. These two limitations of macroeconometric models are accepted as strengths of CGE modelling. Even though CGE functional forms may be regarded as rather straightforward, and parameterization techniques could be improved upon, the approach is consistent with microeconomic theory, and permits a differential treatment of sectors. This last issue is of particular relevance to the analyses in this thesis, since I find that the aggregate effects of the policy-induced shocks conceal very varied impacts at the sectoral and/or regional level.

Macroeconometric modelling, like CGE modelling, is also constrained with regards to the adequacy and availability of data, and for macroeconometric modelling, particular concerns relate to the time consistency of the data being used and the ability to model structural shifts over time. In fact, one of the key advantages of macroeconometric modelling – the ability to reliably estimate parameter values from time series data – constrains its use for the purpose of the research presented in the preceding chapters. Insufficient time series data exist, particularly at the regional level, to be able to fully estimate a sufficiently-detailed macroeconometric model of the whole economy.

Lastly, macroeconometric modelling faces the same reliance on the modeler's judgement over the choice of the structural specification of the model, functional forms and so forth. Whereas in CGE modelling there may be biases in terms of the modeller's choice of production technology, closure rule and source of exogenously determined parameters, the judgement and expertise of a macroeconometric modeler will be reflected in their choice of model structure amongst, for example, Keynesian, monetarist or an ad hoc alternatives, or in the treatment of expectations or the incorporation of time varying parameters. However, a macroeconometric modeler can test the appropriateness of some model specifications, such as functional forms, subject to adequate data requirements, whilst a CGE modeler must often rely on other work to justify their choices.

Dynamic optimization and optimal control theory models also have their uses in policy analysis: they are able to trace the dynamics of the economy over time, and aid the selection of the optimal time path of policy changes according to specified criteria. Macro-based models of this type, however, are generally not capable of modelling distributional effects, whereas micro-based models in this category tend to be based on partial equilibrium principles, precluding their ability to model the economy-wide interlinkages and feedback effects that are the stronghold of CGE models. These models have in common the problems of data adequacy, parameterization and model specification that CGE models face. The dynamic complexity of the model structures often require reliance on exogenously specified parameters, and the same issues arise relating to the influence of the modelers judgement, expertise and biases on model specification, as for CGE modelling.

7.5 Dynamic Stochastic General Equilibrium models

Other modern macroeconomic models in use for policy analysis include dynamic stochastic general equilibrium (DSGE) models. Early DSGE models were developed to study how real shocks to the economy might cause business cycle fluctuations (Kydland and Prescott, 1982). The models incorporate rational, infinite-lived, identical households who maximise intra- and inter-temporal utility. They are closely related to CGE models in terms of specification and computation: they are founded on microeconomic assumptions about tastes, technology, constrained optimisation and general equilibrium, and have often relied on calibration rather than estimation for parameterisation. In contrast to CGE models, however, agent maximisation occurs within a stochastic, rather than a deterministic, environment. One advantage of the stochasticity of the model is that it lends itself to econometric estimation and the fitting of time series data. Recent DSGE models have become more complex, with increased structural shocks, real and monetary frictions and adaptive expectations being considered within the framework for added realism and improved empirical fit to the data. There have also been advancements in procedures to formally parameterise DSGE models (see Canova, 2007). However, the complexity of DSGE models means that they are difficult to solve and analyse. Accordingly, they tend to abstract from sectoral and regional detail and incorporate fewer variables, making them less useful for the type of policy analysis conducted within this thesis. They are more appropriate for examining the dynamics of the aggregate economy, and have been used extensively for monetary policy analysis (Clarida et al., 1991). Although the DSGE methodology has yet to be used for regional policy analysis[30], Rickman (2009) suggests that the techniques for estimation and dynamic fitting of DSGE models provide important insights for the future research direction of CGE analysis.

8. Conclusion

In recent years, quantitative analysis of the effects of policies on economic outcomes has grown sharply, and CGE modelling lends itself well to this process. A carefully constructed model will have a transparent and theoretically consistent model structure, which allows an understanding of the economy-wide consequences of a policy change, from both a sectoral and a spatial perspective. These characteristics led Hertel (1997, p.2) to emphasize the value of CGE analysis to policy design in that it provides policy makers with the opportunity ‘to apply their own insights into particular problems within a consistent economy-wide framework’.

The sharp policy focus of CGE models has meant that the technique has been a feature of the policy appraisal process of many governments and governmental organisations worldwide. International organisations such as the OECD and the World Bank also

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[30] To my knowledge, at the time of writing, there exist no published regional DSGE models.

make use of CGE analyses, either by means of in-house modelling teams or consultancy projects. The topics addressed are wide ranging, from global trade analysis to environmental issues and regional development initiatives. These CGE modelling projects are intended to complement policy analysis conducted via different modelling approaches, rather than to be a substitute for all other types of analysis. As with all modelling techniques, the results will be subject to error, and the quality of the analysis will depend on the appropriateness of the policy topic, the structure of the model, the suitability of the model specification and so forth. The advantage of the CGE approach is its ability to measure and describe the ultimate impact of exogenous changes on aggregate economic activity in a theoretically consistent way. Their usefulness in policy analysis is based less on their predictive accuracy, and more on their ability to shed light on the interactions and feedbacks among all of the markets in the economy.

Chapter 3[1]

Regional Policy Spillovers: Evaluating the National Impact of Demand-Side Policy in an Interregional Computable General Equilibrium Model of the UK

1. Introduction

In this chapter I examine the net national impact of a policy-induced regional demand shock, using an interregional CGE model of the UK economy. During its time in office, the UK Labour government has promoted devolved and regional policy as a means of increasing national growth and reducing economic imbalances between the regions (Department for Trade and Industry, 1998, 2003a). Despite this shift towards decentralised decision-making and responsibility, few researchers have evaluated the impact of local development policy outwith its immediate target area. A substantial body of literature considers the effect of regional policy on the recipient regions (Taylor, 2002; Wren, 2003). However, studies that consider the effect of regional policies on other regions or the national economy are rare. In this chapter, I aim to address the issue by providing a more comprehensive evaluation of regional policy, focusing on both the regional and national implications of a policy-induced demand shock.

Until recently, the official government view was that local development policy had no net effect on the national economy (HM Treasury, 1997). Regional policy was traditionally viewed as a 'zero sum game', such that any employment gains in one area would be exactly offset by losses elsewhere, thus ruling out the possibility that regional policy could have welfare-enhancing effects at the national level. This suggests that regional policy was viewed as being of limited use: it could have a redistributive impact, but could play no role in enhancing overall economic performance. This may have been

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[1] The research of this chapter has been submitted in part to the journal Environment and Planning A and is currently at the 'revise and resubmit' stage.

a factor in discouraging comprehensive research into the national effects of regional policy.

More recently, the Treasury has moved away from the assumption of full crowding out, though only with regard to supply-side policies (HM Treasury, 2003)[2]. The Treasury's shift in perspective - albeit a partial one - acknowledges the potential for regional policy to provide national economic gains. Furthermore, it makes the policy-making process more complex: the impact of local development policies on both the target and non-target region ought to be considered, and both equity and aggregate effects become potentially significant.

This change in emphasis strengthens the need for an examination of the spillover effects of local development initiatives on other regions and for identifying and measuring their impact on the UK economy. In this analysis, I consider the system-wide effects on the Scottish, rest of UK (RUK), and UK national economies of a policy-induced regional export shock which is applied to the Scottish economy. Policy simulations are carried out in a two-region CGE framework of the Scottish and RUK economies, AMOSRUK, which is an interregional variant of the single region CGE framework for Scotland, AMOS[3]. As for any exogenous economic shock, assumptions concerning the exact configuration of the regional and national labour markets will have important implications for the macroeconomic effects of the demand stimulus. In this chapter, I incorporate alternative hypotheses regarding wage-setting and migration behaviour, according to popular views of how regional labour markets operate, to identify the significance of these assumptions for the model results.

Several studies consider the regional multiplier responses to an exogenous change in demand in single-region CGE models, and compare the results to a fixed-price I-O or

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[2] These most recent guidelines for the appraisal and evaluation of UK government policy still do not explicitly acknowledge that demand disturbances can have a national impact.

[3] A summary description of the AMOSRUK model is provided in Section 2 of this chapter, and a full model listing is presented in Appendix A.

Social Accounting Matrix (SAM) model which is embedded in a CGE framework (Harrigan and McGregor, 1989; Koh et al., 1993; West, 1995). The key contribution of these studies is to demonstrate that limited factor supplies and regional price and wage flexibility result in smaller CGE multipliers relative to the I-O multipliers. More recently, a number of variants of the AMOS and AMOSRUK frameworks have been used to investigate the implications of demand-side stimuli that replicate current policy issues. Gillespie et al. (2001b) simulate the multi-period effects of an FDI-related export stimulus, though in the context of the standalone AMOS CGE model of the Scottish economy only. Gillespie et al. (2001a) consider the implications of a demand injection which is related to investment expenditures, combined with an increase in export demand. The authors also use the single region AMOS model, and they report the adjustment path of the economy over time. In McGregor et al. (1999), the authors use the two-region AMOSRUK model to conduct an interregional investigation of the effects of a regional export shock, though the analysis is restricted to long-run simulations only. In this chapter, I conduct a more comprehensive approach to evaluating the effects of a regional policy-induced demand stimulus. In doing so, I use the two-region AMOSRUK model to conduct multi-period simulations of the UK-wide effects of a regional policy shock. I use a wider range of labour market configurations than those analysed previously, and also incorporate an updated base year SAM dataset.

The analysis of the policy issue on both a multi-regional and period-by-period basis not only provides a contribution to the existing literature, but also highlights some important issues for current regional policy-making and evaluation practices. The approach enables me to identify the post-shock adjustment path of the economy under different assumptions regarding the operation of the labour market, rather than only the long-run equilibrium results for each of the scenarios. Accordingly, I consider whether policy assumptions that are 'best' or 'worst' performing in the long-run are similarly so in the short-run. The objective here is not to categorise the results in terms of their economic impact per se (evidently the Treasury is not in a position to choose between labour market closures in any case). Rather, the intention is to highlight that the policy outcomes can vary across different time frames of analysis, and that the variation can be in either direction, depending on the configuration of the labour market. In the UK, policy makers have a ten year time horizon for the evaluation of local development initiatives (HM Treasury, 1995). The period-by-period analysis in this chapter - which extends over the duration of this evaluation period and beyond - helps to identify whether there are adjustments that occur outwith policy makers' period of consideration which could significantly affect decision-making. Furthermore, taking account of the time component of the effects of regional policies allows me to examine any discrepancies in the relative speed of adjustment of the regional economies, which would likely be important in determining the most appropriate policy action.

The choice of policy change that I consider is in close accord with current government policy in the target region. Although regional development policy has previously focussed mainly on supply-side issues, demand-side policies have also become important in recent years. The Scottish 'Government Economic Strategy' (Scottish Government, 2007a) sets out its objectives for improving Scottish international competitiveness and increasing Scottish exports, and one role of Scottish Enterprise – Scotland's economic development agency – is to improve global trade links and help exporters become more competitive suppliers to overseas markets, through its 'Global Connections' theme[4]. I do not focus on the different types of policies that could help to achieve this effect in any detail[5]. However, I do note that the Scottish government's current energy policy, which emphasises the domestic and export growth opportunities associated with Scotland's renewable energy sector (Scottish Government, 2008a), could ultimately generate an export shock of the type discussed here. Some aspects of UK and Scottish renewable energy policy are considered in more detail in Chapter 6, where I

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[4] This comes ultimately from 'A Smart, Successful Scotland: Ambitions for the Enterprise Networks', the Scottish Executive, January 2001.

[5] Although an export demand shock is an interesting one to consider in accordance with the current objectives of the regional government, I do note that the effects of demand stimuli would vary with the type of demander, for example, via different terms of trade effects.

conduct a UK-wide demand-side policy simulation that relates to domestic and export demand for marine energy devices.

The demand stimulus featured in this analysis is assumed to be an entirely costless exogenous increase in export demand in the Scottish manufacturing industry. Such a demand stimulus could arise, for example, as an indirect consequence of international environmental obligations to reduce carbon emissions such as those embedded in the Kyoto Protocol (United Nations, 1998, 2009). World-wide interest in renewable energy technologies has increased in recent years in response to legally-binding emissions targets and the Scottish economy, which has a large capacity of renewable energy resources and a growing research and production base for renewable energy devices such as wave and tidal turbines, is well-placed to benefit from export demand for such devices.

The remainder of this chapter is structured as follows. In section 2 I introduce a summary version of the AMOSRUK model. I discuss alternative visions of the labour market in Section 3. In Section 4, I present the results of simulating an exogenous regional demand shock within the AMOSRUK framework under different assumptions regarding the characteristics of the regional labour markets. For each of the labour market scenarios, summary tables showing the impact of the shock on key economic variables are presented within the text of this section. For ease of reference, all of the figures associated with the discussion of the results are provided in Appendix D. In Section 5, I discuss various policy implications of the analysis, alongside concluding comments. Further details of the model structure, labour market configurations and additional detail on the model properties are provided in Appendices A, B and C respectively.

2. AMOSRUK: a CGE framework

AMOSRUK, the interregional version of the AMOS simulation framework, is a CGE model of the UK economy[6]. A full description of AMOSRUK, including model equations, is presented in Appendix A, and a summary of the key model characteristics is provided below. The model structure is a flexible one, and a range of model closures corresponding to different time periods of analysis and labour market options is available. The choice of mode closure is clearly an important one that will have significant implications for model results. In this chapter, I focus on the national population constraint, and its impact on regional wage determination. The way in which the labour market closures are used to vary the operation and spatial impact of this constraint is given in greater detail in Section 3.

The model structure includes two endogenous regions - Scotland and the RUK - and one exogenous region - the rest of the world (ROW). Scotland makes up around 8.5% total UK output, employment and population. There are three transactor groups in each region - households, firms and the government - and three commodities and activities - manufacturing, non-manufacturing and sheltered. There are four main components of final demand: household consumption, investment, government expenditure and exports to the other region and the ROW.

The basic data set for the model is an interregional SAM for 1999. This data set provides a 'snapshot' of the Scottish and RUK economies for that year, highlighting the relative size of the economies and the linkages that exist between sectors and regions. The SAM is an augmented I-O table with transfer payments between economic agents and factors of production[7]. It covers all intra-regional, interregional and international transactions in the economy that year. The structural data embedded in the SAM are

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[6] Greenaway et al. (1993) provides a general appraisal of CGE models and Partridge and Rickman (1998, 2008) review regional CGEs.

[7] Allan et al. (2004) explains the construction of the I-O and SAM databases for the AMOSRUK CGE model used here.

used to ascribe actual values to some of the parameters of the functional forms in the model system (for example the relative size and import intensity of sectors). Other parameter values are determined exogenously (for example migration function parameters and elasticities of substitution), drawing from existing literature. A final set of parameter values are determined through calibration of the model. Where econometrically parameterised relationships have been imposed, these have been determined using annual data. Each 'period' in the model is therefore interpreted as a single year.

In production, local intermediate inputs are combined with imports from the other region and the ROW via an Armington link (Armington, 1969). This composite input is then combined with labour and capital (value added) to determine each sector's gross output. Production functions at each level of the production hierarchy can be of Constant Elasticity of Substitution (CES), Cobb-Douglas or Leontief forms. In this paper, CES production functions are imposed throughout, with the exception of the very bottom level of the production function hierarchy, where commodity substitution at the regional level is determined by Leontief functions – see Figure A.1, Appendix A.

Consumption demand is linear in real income and homogenous of degree zero in all nominal variables. Real government demand is exogenous. Both interregional and international exports are price sensitive. However, while non-price determinants of export demand from the ROW are taken to be exogenous, export demand to the other UK region is fully endogenous, depending not only on relative prices, but also on the structure of all elements of intermediate and final demand in the other region.

A significant feature of the model is the between-period updating of capital stocks and the labour force. For the capital stock, gross investment is given by an explicit capital-stock adjustment mechanism. In each period investment demand from each sector is a proportion of the difference between actual and desired capital stock, where desired capital stock is a function of commodity output, the nominal wage and the user cost of capital. For the labour force, it is assumed that there is no natural population increase and that international migration can be ignored. Therefore, the only means of adjusting the regional labour forces is through interregional migration or an increase in labour market participation. This is explained in greater detail in the next section. In addition, the AMOSRUK model also provides the opportunity to impose constraints on the regional balance of payments and on public sector net transfers to the region. However, in this analysis, no macro constraints are imposed other than the labour market closures mentioned above.

For the simulations, the main parameter values are as follows: the elasticity of substitution in the CES production functions is set at 0.3 (Harris, 1989)[8] and the Armington assumption is applied to both interregional and international trade with an elasticity of substitution of 2.0 (Gibson, 1990). The parameter determining the speed of adjustment from actual to desired capital stock is set at 0.5, following econometric work on the determination of investment in the Scottish economy.

3. Alternative visions of the labour market

In evaluating the full spatial impact of a demand shock, in this study I focus on a population constraint that can operate at the regional or national level. I define a region as having an effective long-run population constraint when an increase in regional employment leads to an increase in long-run regional real wages. Thus where an increase in employment is not directly associated with an increase in long-run real wages - for example due to the presence of fixed real wages or in-migration - no effective long-run population constraint exists. The main impact of the constraint feeds through to the

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[8] This is consistent with more recent estimates of the elasticity of substitution between capital and other factors of production in the UK. Barnes et al. (2008) estimate an elasticity of substitution in the region of 0.32 to 0.42 for the UK. In the Bank of England Quarterly Model - the macroeconomic model developed for use in preparing the Monetary Policy Committee's quarterly UK economic projections - the parameter is set at 0.317 (Harrison et al., 2005). For US data, the elasticity of substitution between capital and labour is often estimated at close to unity (e.g. Adkins et al., 2003), however, some US estimates are close to the UK value of 0.3 used in this analysis (e.g. Chirinko et al., 2002).

economy via its effect on wage setting. For example, where the regional real wage is determined by a local bargaining process, a rise in employment leads to an increase in the regional real wage and a reduction in competitiveness. Interregional migration can, however, ease this labour market pressure, in this example by attracting net in-migration. In the simulations to follow, my objective is to determine the significance of the population constraint in influencing the spatial impacts of the policy-related shock. I consider five labour market scenarios - summarised in Table 3.1. Each of these is intended to represent a stylised version of conventional labour market configurations that are common in the labour market and regional macroeconomic literature.

Table 3.1 Simulation scenarios

	Population	**Regional Wage Setting**		**Effective Long-Run Population Constraint**	
		Scotland	**RUK**	**Regional Level**	**National Level**
Quasi IO	Fixed at the regional level	Fixed real wage	Fixed real wage	No	No
Regional Bargaining	Fixed at the regional level	Bargaining	Bargaining	Yes	Yes
Flow Migration	Fixed at the national level	Bargaining	Bargaining	No	Yes
Wage Spillover (1)	Fixed at the regional level	Adoption of RUK nominal wage	Bargaining	Yes (RUK) No (Scot)	Yes
Wage Spillover (2)	Fixed at the national level	Adoption of RUK nominal wage	Bargaining	Yes (RUK) No (Scot)	Yes

3.1 Quasi I-O

The first scenario incorporates fixed real wages in both the Scottish and RUK economies. There is no interregional migration of the labour force, so that regional employment is determined solely by regional labour demand. This configuration involves no effective population constraint at either the regional or the national level. Increased employment is met by increased regional labour market participation, with no change in real wages, so neither region suffers adverse competitiveness effects generated specifically through the labour market as export demand expands. The nominal wage might change but only in response to changes in the regional consumer price index (CPI). Capital fixity dictates supply restrictions, so that marginal costs and prices rise in the short-run as output expands. Over time, however, investment optimally adjusts capital stocks, relaxing capacity constraints, and ultimately the economy operates like an extended I-O system (McGregor et al., 1996b). In this scenario, the economy is capital-constrained in the short -run, though in the long-run there are no supply-side constraints. However, in so far as the national economy is believed to be constrained by supply side factors in the long-run, this renders the Quasi IO closure subject to the same limitations as an I-O model (discussed in Section 7.3, Chapter 2). For the purposes of the research in this thesis, the Quasi I-O closure acts as a useful benchmark, and the simulation results offer important insights into the forces at work during the adjustment process of the regional economies.

3.2 Regional Bargaining

The second simulation scenario involves a set-up where population is fixed in each region as before, but differs from the Quasi I-O configuration in that wages are determined by a bargaining process. The particular bargaining function adopted is the econometrically-parameterised relationship identified by Layard et al. (1991):

$$\ln\left[\frac{w^I}{cpi^I}\right] = \beta^I - 0.113\ln u^I \tag{3.1}$$

where:

w is the nominal wage rate

cpi is the consumer price index

u is the unemployment rate

β is calibrated to ensure that the model replicates the base year data set, and

the I superscript indicates the region.

A population constraint operates in each region in this configuration. In both regions, real wages reflect the tightness of the regional labour market, which varies with the regional unemployment rate (Minford et al., 1994). Empirical support for this 'wage curve' is widespread across countries, including for the UK, and in a regional context[9]. This configuration is intended to reflect the notion of a conventional wage curve operating at the level of the region.

3.3 Flow Migration

The third model scenario involves real wage bargaining at the regional level, as in the previous Bargaining set-up, but also introduces interregional migration to allow for population adjustment. Migration flows in one period serve to update the population stock in the next period. The Scottish rate of in-migration is positively related to the Scottish/RUK ratio of the real consumption wage and negatively related to the Scottish/RUK ratio of unemployment rates, in the spirit of Harris and Todaro (1970)[10]. The specific form of this equation is in accordance with the econometrically parameterised interregional migration function of Layard et al. (1991):

$$\ln\left[\frac{m^S}{L^S}\right] = \delta - 0.08\left[\ln u^S - \ln u^R\right] + 0.06\left[\ln\left[\frac{w^S}{cpi^S}\right] - \ln\left[\frac{w^R}{cpi^R}\right]\right] \tag{3.2}$$

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[9] See, for example, Blanchflower and Oswald (1990, 1994). More recent empirical evidence also suggests that the wage curve is still relevant to the UK economy, including in a regional context: see Barth et al. (2002), Blanchflower and Oswald (2005) and Montuenga et al. (2003).

[10] Harris and Todaro (1970) suggest that in-migration will occur to a local area (of developing countries) if (among other factors): wages increase, unemployment decreases or job creation increases, thereby increasing expected income in that area.

where:

m is net-inmigration

L is population

δ is a calibrated parameter that ensures zero net migration (the equilibrium condition) for the base year data, and

S and R indicate Scotland and the RUK respectively.

The topic of interregional migration in the UK has been an important one lately, with some authors proposing that native workers are finding it increasingly attractive to migrate to other areas in the UK in search of employment, as a result of competition with international migrant workers concentrated in areas such as the South of England (e.g. Hatton and Tani, 2005). Indeed Biswas et al. (2008) find that interregional migration in the UK has been significant in recent years (including between Scotland and the RUK), and has been increasing over time. Several micro- and macroeconomic factors have been put forward as determinants of UK interregional migration, with a number of studies suggesting that the Harris and Todaro-type migration function is relevant to the UK labour market[11]. Allowing for interregional migration in this scenario also means that the results can be considered in the context of the Scottish government's objectives for population growth[12].

In this set-up, the presence of migration allows for a unified national labour market: an increase in regional demand lowers regional unemployment and increases the real wage, inducing migratory flows into that region. In long-run equilibrium, the presence of migration re-imposes the original ratio of regional wage and unemployment rates (see

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[11] For example, Hughes and McCormick (2000) find that relative regional wages in the UK significantly influence migration between regions, and Pissarides and Wandsworth (1989) find that the level of regional unemployment significantly affects the probability of migration for an individual. Also, studies for the US include Treyz et al. (1993), who find that net migration is significantly related to, among other factors, relative employment opportunities and relative real wages.

[12] The Scottish 'Government Economic Strategy' (Scottish Government, 2007a) identifies that Scottish out-migration is a policy concern, and notes that population growth has lagged significantly behind that of the RUK during the last ten years. Population targets are set in line with average EU-15 population growth for the period 2007-2017.

Appendix B). In this scenario, the population constraint works only at the national level; migration eases labour market pressures for one of the two regions.

3.4 Wage Spillover (1) and (2)

In the Wage Spillover cases the RUK acts as the lead region and Scotland as the follower. Real wages in the RUK are determined by regional bargaining, as in Equation (3.1), while the Scottish economy accepts the nominal wage that is set by the RUK. This labour market set-up is intended to incorporate an interregional variant of the traditional Keynesian macroeconomic vision of a region in which nominal wages are fixed. This has often been motivated in terms of a national bargaining system. In the present case, Scottish nominal wages are not fixed, but they are determined outwith the region. The set-up captures the scenario whereby unions negotiate at the national level, and the outcome of the bargaining process feeds through to the regions, who are nominal wage takers[13]. Wage Spillover (1) incorporates no interregional migration, whilst in Wage Spillover (2), interregional migration is allowed for, according to Equation (3.2).

In the Scottish region, there is essentially no population constraint, since regional wages do not directly respond to regional labour market pressures. In the RUK region, however, there is an effective population constraint, since nominal national wages reflect the tightness of the labour market in the RUK. The UK economy as a whole is therefore population constrained.

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[13] This labour market configuration also incorporates the notion of inflationary wage spillovers, whereby inflationary wage pressures can differ across regions of the UK and wage pressures in one ‘lead’ region, such as the South East of England, can influence wages in other regions. A number of authors have considered the extent to which wages in one region of the UK are influenced by wages set in other regions, including Manning (1994) and Molho (1982). Armstrong and Taylor (2000) suggest that nationally bargained wages, and the corresponding wage rigidity that this introduces to regional labour markets, could be one explanation, amongst others, for regional unemployment differentials across the EU (pp. 170-171).

4. Simulation results

This analysis considers the system-wide effects on Scotland and the RUK of a demand shock to the regional economy: an increase in Scottish exports to the ROW. The choice of an export-led demand shock is partly conceptual. The effects of a demand disturbance within a conventional, purely demand-driven single and multi-regional I-O model are already well understood[14]. Thus, comparison of CGE-based results relative to that of an I-O framework provides significant insight into the combined effects of the sectoral linkages and national constraints. The choice of an export-led shock, in particular, is appropriate since it is a good example of a straightforward demand disturbance, and one that is often considered in the regional policy literature. Furthermore, the effects of an export shock are of interest due to this type of stimulus being closely related to current policy concerns in the target area, as outlined previously.

The simulation method involves a 5% step increase in ROW exports from the Scottish traded sectors (i.e. the manufacturing and non-manufacturing traded sectors). This involves an outward movement of the ROW demand schedule for Scottish manufactured goods and services, by 5%. The model is run forward for 50 periods with the values of all other exogenous variables held constant, and the changes from the initial base-period value are reported for the key variables. In all cases, capital stock is updated between periods, and in the Flow Migration and Wage Spillover (2) scenarios the regional populations are adjusted in a similar manner. In the other scenarios, the regional populations remain constant.

The model calibration process takes the economy to be initially in long-run equilibrium. This means that if the model is run forward with unchanged exogenous variables and parameters, the endogenous variables continuously take their initial values. Introducing a step change drives the economy towards a new long-run equilibrium and it is the paths

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[14] McGregor et al. (1996b), and McGregor et al. (1999).

to these new comparative static equilibria that are reported here. The different model configurations generate both different long-run equilibria and different adjustment paths.

I discuss the simulation results for each model configuration in turn. I consider the long-run versus short-run impacts, along with the relative effects in each region. For the purposes of this research, I use the terms 'short-run' and 'long-run' more flexibly than that suggested by a strict analytical definition. I refer to the 'short-run' as being a period of 0 to 5 years after the policy shock, and to the 'long-run' as a period of around 50 years post-shock. I also make use of the term 'evaluation period' which refers to the period 0 to 10 years following the shock, which is the time period considered by HM Treasury for the purposes of evaluating local development policies (HM Treasury, 1995).

In Appendix D, Figures D.1 - D.16 show the trajectories for the change in key variables relative to base for the five model configurations: Figures D.1 - D.7 report the effects on the Scottish economy; Figures D.8 - D.14 provide the corresponding RUK results; and Figures D.15 - D.16 are for the national economy. Within the text, Tables 3.2 - 3.7 summarise the results for key variables. I report aggregate variables in both absolute and percentage terms; the remaining key variables I report in percentage terms. Some variables (such as capital rental rates and commodity output prices) do vary across the three sectors, but in some instances, to aid clarity, a weighted average of the change across all sectors is presented[15]. Each variable is expressed in terms of its change (absolute or percentage) relative to base.

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[15] A weighted average of the change in exports across all three sectors is provided in the summary tables. For the simulations, a 5% ROW export demand shock is imposed on the Scottish manufacturing and non-manufacturing traded sectors, but not on the sheltered sector. In this model, the sheltered sector includes industries in which there is relatively little external trade, though the level of exports is still positive. Imposing a 5% export shock on the traded sector increases total exports by approximately 4.8%, assuming there is no exogenous change in sheltered sector exports.

4.1 Regional economy results

4.1.1 Quasi I-O: Scottish economy results

Figure D.1 shows the change in Scottish GDP relative to base for the five model configurations. In all cases, Scottish GDP increases over time towards a new, stable, equilibrium. The long-run increase relative to base is greatest for the Quasi I-O configuration, with GDP 1.41% above its base value by period 50 (Table 3.2). The results from this configuration are used as a benchmark against which the other scenario results can be compared.

The positive demand shock boosts commodity outputs in the traded sectors, and also in the wider economy via increased demand for intermediate inputs, though the effects are less significant in these sectors. In the long-run, in each sector, all inputs rise by the same proportionate amount, which equals the growth of output in that sector, so that constant technical coefficients are maintained, and all prices return towards their base-period equilibrium values in this set-up (Figure D.2). This confirms previous long-run simulation results for similar model configurations in a single region context: a small region with fixed wages and no migration will encounter demand-invariant prices, which motivates fixed production and consumption coefficients (McGregor et al., 1999). This paper extends the existing research to a two-region CGE analysis, but the absence of population and supply-side constraints makes the framework I-O-like, and the long-run equilibrium exhibits the I-O characteristics of constant technical coefficients and constant prices.

In the shorter-run, during the adjustment process, capital fixity imposes supply restrictions. As output expands, prices rise in the short-run. Capital rental rates increase on average across all sectors by 1.41% and 1.30% relative to base in periods 2 and 3 respectively. There is upward pressure on the price of commodity outputs and value added in the traded sectors, and also on the overall CPI. Sheltered sector prices rise because of the general increase in consumption demand, and also because intermediate inputs from this sector are required in the traded sector production process, but the effects are less significant than in the traded sectors.

In line with the output expansion, the positive demand shock increases the derived demand for labour across all sectors. The long-run employment effects are strongest in this scenario out of all the labour market configurations (Figure D.3), with total employment 25,138 (1.33%) above base by period 50. The Scottish real wage rate is held constant throughout the adjustment period (Figure D.4). So in this scenario, the Scottish economy does not suffer adverse competitiveness effects generated specifically through the labour market as export demand expands. As output increases, nominal wages do rise (Figure D.5), in response to the increase in the regional CPI in the shorter-run (Figure D.2), and this has implications for the region's competitiveness. In the long-run, however, prices and nominal wages return to their base values in the Quasi I-O scenario, and this labour market configuration results in the highest increase in ROW exports over base (Figure D.6).

Table 3.2 Quasi I-O summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	£275.43m	£44.43m	£549.08m	£200.5m	£880.37m	£694.63m
	0.44%	0.01%	0.88%	0.03%	1.41%	0.10%
Total employment	9,913	1,442	16,611	5,965	25,138	19,220
	0.52%	0.01%	0.88%	0.03%	1.33%	0.09%
Traded sector employment	0.68%	0.01%	1.13%	0.04%	1.69%	0.11%
Sheltered sector employment	0.18%	0.00%	0.34%	0.01%	0.53%	0.05%
CPI	0.31%	0.08%	0.21%	0.06%	0.01%	0.01%
Commodity output prices	0.47%	0.08%	0.29%	0.06%	0.02%	0.01%
Price of value added	0.69%	0.08%	0.40%	0.07%	0.02%	0.01%
Nominal wage	0.32%	0.08%	0.21%	0.06%	0.01%	0.01%
Real wage	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Exports to the other region	-0.93%	1.25%	-0.47%	1.42%	0.06%	1.56%
Exports to ROW	3.67%	-0.15%	4.33%	-0.12%	4.87%	-0.02%

4.1.2 Quasi I-O: RUK economy results

In the Quasi I-O case and for the RUK economy, the regional export shock in Scotland also results in an increase in both short-run and long-run GDP, and the results under this scenario are significantly stronger than for the other four scenarios, and always expansionary (Figure D.8). This reflects the absence of RUK population constraints in this model set-up. As is apparent from Table 3.2, in this scenario the long-run impact on the RUK in terms of the absolute change in GDP is almost as large as the impact on Scotland itself, reflecting the high trade linkages between the two economies. The size of the impact as a percentage of GDP is, as expected, less significant for the RUK economy relative to Scotland, owing to the direct effect of the shock on the Scottish economy.

The source of the stimulus in the RUK economy is an increase in demand for RUK intermediate goods from the Scottish economy and, as activity expands in Scotland, for final consumption and investment goods. As with the Scottish economy, real wages remain fixed (Figure D.11), so that, as output expands, the RUK economy does not experience negative competitiveness effects generated directly through the labour market. Nominal wages increase in response to a rise in CPI in the short-run, but both variables move back towards their base values over time (Figures D.12 and D.9 respectively).

In the short-run, as RUK commodity outputs increase across all sectors, prices increase relative to base (Figure D.9). Therefore a negative external competitiveness effect does exist at this stage: exports to the ROW fall by 0.16% relative to base in the period immediately following the shock (Figure D.13). Nevertheless, exports to Scotland increase by 1.16% relative to base in the same period (Figure D.14), contributing to an overall relative GDP stimulus (Figure D.8). Over time, capacity constraints relax, prices move back towards their base year values and the negative external competitiveness effect is removed.

Although the overall impact of the Scottish export shock is an increase in long-run GDP in both regions, the effects of the stimulus are much slower to materialise in the RUK compared with Scotland. In period 3, the relative increase in Scottish GDP is over 30% of its long-run period 50 value. In contrast, RUK GDP in period 3 is just over 6% of its period 50 value (Table 3.2). This is partly explained by the differing composition of each region's export market. Whilst exports to the RUK account for around 50% of Scotland's total exports, exports to Scotland constitute only around 13% of the RUK's total exports. The relatively small share of the RUK's other-region exports means that the RUK has fairly limited exposure to the demand shock stimulus that feeds through from the Scottish economy[16].

Furthermore, the interregional transmission mechanism contributes to the delayed adjustment for the RUK economy. The initial shock felt by both economies, albeit originating from a pure demand disturbance in Scotland, embodies both a demand stimulus and an adverse supply shock. The Scottish economy receives an initial demand injection from an increase in ROW manufacturing exports. Capital fixity brings about an adverse supply reaction in the short-run, but the direct impact of the ROW demand stimulus is sufficient to dominate this, leading to an overall increase in Scottish GDP, even in the short-run (Figure D.1)[17]. Over time, as capacity constraints relax, the full effects of the demand shock are transmitted to the wider economy. The RUK economy, in contrast, does not receive the immediate ROW demand stimulus. Rather, the demand boost for the RUK economy is generated indirectly from an increase in demand for intermediate and final goods from Scotland, and these effects take time to feed through. There is a limited short-run demand stimulus in the RUK, and a corresponding adverse supply reaction, and the demand effects do prevail to generate an increase in GDP in the periods following the shock (Figure D.8)[18]. But the immediate effects of the shock are muted relative to the ultimate impact: only when capacity constraints are optimally adjusted in Scotland are the entire effects of the demand disturbance transmitted to the RUK via interregional trade linkages. This results in a protracted adjustment period for the RUK economy.

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[16] Preliminary simulations of an equivalent ROW exports shock on the RUK economy support this suggestion. The analysis reveals that there is a delayed period of adjustment for the Scottish economy relative to that of the RUK in two of the labour market scenarios, but to a much lesser extent, and the delay is not apparent for the other labour market configurations.

[17] This is true for the Scottish economy across each of the labour market scenarios.

[18] This is true for the RUK economy across all the model scenarios, except those including migration. See Sections 4.1.6 and 4.1.8 for a discussion of the effects of migration in reducing RUK GDP relative to base in the short-run.

The CGE results reported above thus reveal more complex economic interactions and adjustment mechanisms compared with straightforward I-O analysis, and this has direct implications for the non-target region effects. Whereas under I-O analysis an increase in ROW exports for Scotland constitutes a pure demand shock, the active supply-side response embodied in CGE analysis means that the other region effects are not confined to the demand side. This suggests that I-O analysis would provide a poor approximation of the effects of the shock in the short-run in the presence of a non-passive supply-side.

4.1.3 Regional Bargaining: Scottish economy results

The introduction of bargained real wages, either without migration (the Bargaining scenario), or with migration (the Flow Migration scenario), reduces the size of the relative GDP stimulus in Scotland, as the responsiveness of wage rates gives rise to negative competitiveness effects that are maintained into the long-run (Figures D.4 and D.5).

In the case of the Bargaining scenario, the relative increase in GDP is the lowest out of all the configurations, with the long-run change in GDP less than 50% of the value in the other three cases (Figure D.1). In this set-up, the export stimulus increases the derived demand for labour (Figure D.3). With no interregional migration, real wages rise, reflecting the tightness of the regional labour market (Figure D.4). Commodity output prices therefore rise relative to base, as does the overall CPI (Figure D.2). This represents a significant negative competitiveness effect: real wages are 0.56% higher than base by period 50 (compared with no change in the Quasi I-O case) and economy-wide prices are 0.32% higher (compared with 0.01% in the previous scenario). Furthermore, while the negative competitiveness effect that occurred in the Quasi I-O case was a short-run and indirect effect, in the present set-up the effect remains significant for the duration of the simulation period, and operates directly through the labour market.

As a result of the reduction in Scottish competitiveness relative to that in the Quasi I-O case, the increase in Scottish exports to the ROW is lower (Figure D.6). This is reflected in a weaker overall GDP stimulus, and accounts for a more subdued increase in total Scottish employment relative to base over the period (Figures D.1 and D.3)[19].

Table 3.3 Bargaining summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	£173.85m	£23.81m	£296.47m	£77.44m	£359.41m	£124.50m
	0.28%	0.0%	0.47%	0.01%	0.57%	0.02%
Total employment	5,655	610	7,682	1,746	8,818	2,650
	0.30%	0.00%	0.41%	0.01%	0.47%	0.01%
Traded sector employment	0.44%	0.00%	0.61%	0.01%	0.7%	0.02%
Sheltered sector employment	-0.02%	-0.02%	-0.04%	0.00%	-0.04%	0.00%
CPI	0.36%	0.08%	0.35%	0.08%	0.32%	0.07%
Commodity output prices	0.59%	0.08%	0.56%	0.08%	0.53%	0.08%
Price of value added	0.86%	0.08%	0.77%	0.09%	0.71%	0.08%
Nominal wage	0.69%	0.09%	0.83%	0.09%	0.88%	0.09%
Real wage	0.32%	0.00%	0.47%	0.01%	0.56%	0.02%
Exports to the other region	-1.08%	1.25%	-0.85%	1.39%	-0.74%	1.44%
Exports to ROW	3.54%	-0.16%	3.98%	-0.15%	4.13%	-0.14%

4.1.4 Regional Bargaining: RUK economy results

The presence of bargained real wages similarly reduces the GDP stimulus in the RUK economy compared to the effects under the Quasi I-O scenario. In this scenario,

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[19] These results are in line with those of McGregor et al. (1999), which considers the spillover effects and interdependencies between the Scottish and RUK economies in a CGE context. The authors examine a demand shock in the presence of local wage bargaining and no migration, and find that there is some crowding out of the employment injection through reduced competitiveness.

increased demand for RUK intermediate inputs and consumption and investment goods results in a rise in RUK exports to Scotland (Figure D.14). In fact, the changes in RUK exports to Scotland following the shock are fairly uniform over the different labour market configurations. The key factor underlying the different GDP trajectories is the change in RUK exports to the ROW (Figure D.13), which itself is driven by price and competitiveness effects. In the Bargaining scenario, as output expands and the derived demand for labour increases, real wages are bid up (Figure D.11). This reduces RUK competitiveness relative to the Quasi I-O case, leading to a larger fall in ROW exports (Figure D.13) and increasing import penetration. This contributes to a significantly lower GDP stimulus in this case relative to the Quasi I-O scenario. By period 50, GDP is 0.02% higher relative to base in this scenario, compared with 0.10% in the Quasi I-O case.

In the Bargaining set-up, the RUK economy is slower to adjust to the shock compared with the Scottish economy. This is in line with the results from the Quasi I-O case, and reflects the indirect nature of the shock. Furthermore, the relative reduction in GDP that results from the introduction of regional wage bargaining compared with the benchmark Quasi I-O configuration differs for the Scottish and RUK economies. While the existence of bargained real wages leads to approximately a 59% relative reduction in the Scottish GDP increase over base by period 50, compared to the Quasi I-O case, the equivalent figure for the RUK is just over 82%. Thus the responsiveness of wages has a more significant adverse impact on the RUK economy than on the Scottish economy. In Scotland, this GDP reduction effect stems from the impact of weaker international competitiveness and an associated smaller increase in ROW exports over the time period, compared with the Quasi I-O configuration (Figure D.6). In contrast, the GDP reduction effect in the RUK results from both weaker international competitiveness effects that arise as wages are bid up in line with stronger RUK activity, and also from a weaker stimulus coming from the Scottish economy, compared with the Quasi I-O case. Thus the aggregate relative effect on the RUK economy is more significant.

4.1.5 Flow Migration: Scottish economy results

The demand shock also results in a relative increase in Scottish GDP when migration is introduced, together with bargained real wages. In the Flow Migration case, the source of the long-run boost remains the same as in the previous two scenarios: higher export demand increases traded sector outputs, and the boost in activity feeds through to the wider economy.

In this model set-up, the responsiveness of the real wage works to reduce external competitiveness as activity rises, as in the Bargaining scenario. The introduction of migration, however, lessens this adverse effect. In fact, for the Scottish economy, the presence of migration almost fully mitigates these negative competitiveness effects brought about by the presence of bargained real wages. In the longer-run, the relative change in GDP in this scenario is much closer to that of the Quasi I-O scenario, where there is no adverse labour market effect attributable to the responsiveness of real wages, than that of the Bargaining scenario (Figure D.1).

In this set-up, as in the Bargaining scenario, the regional export shock increases economy-wide prices and real wages. The resultant negative competitiveness effects offset, to some extent, the positive demand impact. Whilst in the Bargaining scenario this negative competitiveness effect remains significant throughout the simulation period, the same is not true of the Flow Migration scenario. The allowance for migration means that, following the shock in the Scottish economy, some of the labour supply migrates away from the RUK economy into the Scottish economy, where the unemployment rate is relatively lower and real wages relatively higher than in the base period. Although there remains a UK-wide labour market constraint (zero net migration is assumed in the UK overall), there is considerable easing of labour market constraints in Scotland, but at the expense of a contraction in the RUK labour supply. Thus the presence of interregional migration, and the increase in labour supply in Scotland, works to mitigate the increase in Scottish real wages in the long-run (Figure D.4). By period

50, real wages are only 0.07% above their base values in the Flow Migration scenario, compared with 0.56% in the Bargaining case. The increase in nominal wages is therefore significantly less in the Flow Migration case in the long-run: nominal wages are 0.19% higher than base in period 50, compared with 0.88% in the Bargaining case. The Flow Migration scenario therefore reduces the loss in price competitiveness of Scottish exports. Scottish exports to the ROW are 4.65% higher, compared with 4.13% for the Bargaining set-up. As a result, the long-run GDP increase under the Flow Migration scenario is greater than under the Bargaining scenario, but still lower than under the Quasi I-O set-up. In the latter case, the absence of a national population constraint means that there is no increase in real wages, thus price increases are more subdued in the short-run (and zero in the long-run) and the negative competitiveness effect is least prevalent (Figure D.1).

Table 3.4 Flow Migration summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	£200.06m	£-11.000m	£438.53m	£-106.69m	£808.34m	£-446.68m
	0.32%	0.00%	0.70%	-0.02%	1.29%	-0.06%
Total employment	6,833	-886	12,923	-4,649	22,968	-14,079
	0.36%	0.00%	0.68%	-0.02%	1.21%	-0.07%
Traded sector employment	0.50%	0.00%	0.91%	-0.02%	1.55%	-0.07%
Sheltered sector employment	0.04%	-0.01%	0.18%	-0.03%	0.47%	-0.06%
CPI	0.36%	0.08%	0.30%	0.08%	0.12%	0.09%
Commodity output prices	0.56%	0.08%	0.43%	0.09%	0.15%	0.11%
Price of value added	0.82%	0.09%	0.58%	0.10%	0.18%	0.13%
Nominal wage	0.58%	0.10%	0.47%	0.12%	0.19%	0.16%
Real wage	0.23%	0.01%	0.17%	0.04%	0.07%	0.06%
Exports to the other region	-1.05%	1.27%	-0.69%	1.43%	-0.16%	1.54%
Exports to ROW	3.57%	-0.17%	4.14%	-0.17%	4.65%	-0.20%
Population	8,570	-8,570	27,534	-27,534	59,025	-59,025

4.1.6 Flow Migration: RUK economy results

In contrast to the effects on the Scottish economy, the introduction of interregional migration makes for an overall reduction in long-run GDP relative to base for the RUK (Figure D.8). By period 50, RUK GDP is 0.06% below its base value (Table 3.4). This compares with a relative increase in GDP of 0.1% for the Quasi I-O scenario and 0.02% for the Bargaining closure.

As in the Bargaining scenario, the RUK economy experiences an increase in export demand from the Scottish economy (Figure D.14). But the presence of interregional migration works to counteract the RUK stimulus in the Flow Migration scenario. Owing to the direct effects of the demand shock in Scotland, the short-run real wage increases and the proportionate rise in employment relative to base are stronger in Scotland compared with the RUK (Table 3.4). These changes in the Scottish/RUK unemployment and real wage ratios mean that some of the population flows into the Scottish economy, and the RUK economy experiences an adverse supply shock in the form of a reduced labour supply. In period 50, the RUK population is 59,025 lower relative to base[20].

The increase in demand for RUK goods from the Scottish economy, combined with reduced population, means that there is still upward pressure on commodity output prices and overall CPI in the RUK economy (Figure D.9). As in the Scottish economy, this causes a detrimental effect on RUK exports to the ROW (Figure D.13). In contrast to that of Scotland, however, the overall effect of the demand disturbance in this scenario is a long-run fall in GDP and employment relative to base (Figures D.8 and D.10). The source of the different outcomes is the effect on the regions' labour supply. When both regions have bargained real wages – without migration – each region

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[20] Lisenkova et al. (2008) explores the macroeconomic impacts of demographic change in Scotland in a CGE context, and similarly finds that a tightening of the labour market will have adverse consequences for employment, growth and competitiveness in the Scottish economy.

experiences an increase in output and employment in the short and long-run. This is because the reduced ROW competitiveness – brought about by the responsiveness of real wages – is offset by the demand stimulus. The introduction of migration, however, results in an increase in the labour supply in Scotland and a reduction in the RUK labour supply, which exacerbates the loss of competitiveness in the RUK.

4.1.7 Wage Spillover (1) and (2): Scottish economy results

Both Wage Spillover set-ups provide very similar long-run results for the Scottish economy, and the adjustment path for each of the scenarios is closely related. These configurations result in a relative increase in GDP for the Scottish economy that is less than that for the long-run Quasi I-O outcome, but higher than that of the Flow Migration and Bargaining scenarios (Figure D.1). GDP is 1.35% higher than base in period 50 for both of the spillover closures, with and without migration (Table 3.5). As in the previous scenarios, higher demand in the Scottish traded sectors boosts economy-wide activity. In the Bargaining and Flow Migration cases, the responsiveness of wages means that wage rates rise and bring about a negative competitiveness effect (though in the latter set-up, in-migration of labour supply helps to limit this effect in the long-run). In contrast, in the Wage Spillover cases, it is the factors that determine the RUK nominal wage that determine the Scottish nominal wage, and thus the extent of wider economic activity in the region. Because the Scottish economy is relatively small compared with the RUK, the effects of the Scottish export stimulus on the RUK economy are fairly limited, as are the effects on the RUK real wage and the Scottish nominal wage (Figures D.11 and D.5 respectively). This means that the Scottish economy does not experience the significant negative competitiveness effects that are evident in the Bargaining and Flow Migration cases; hence the comparatively stronger short-run increase in GDP relative to base for these two cases (Figure D.1).

Table 3.5 Wage Spillover (1) summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	£347.11m	£30.87m	£627.44m	£103.31m	£844.57m	£181.43m
	0.55%	0.00%	1.00%	0.01%	1.35%	0.03%
Total employment	12,784	840	19,093	2,476	24,010	4,099
	0.68%	0.00%	1.01%	0.01%	1.27%	0.02%
Traded sector employment	0.84%	0.00%	1.28%	0.02%	1.62%	0.03%
Sheltered sector employment	0.30%	0.00%	0.40%	0.00%	0.49%	0.00%
CPI	0.28%	0.08%	0.17%	0.06%	0.05%	0.10%
Commodity output prices	0.39%	0.07%	0.22%	0.07%	0.06%	0.06%
Price of value added	0.58%	0.08%	0.30%	0.80%	0.07%	0.07%
Nominal wage	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%
Real wage	-0.20%	0.00%	-0.09%	0.02%	0.03%	0.03%
Exports to the other region	-0.80%	1.25%	-0.35%	1.42%	-0.03%	1.50%
Exports to ROW	3.78%	-0.15%	4.44%	-0.13%	4.79%	-0.11%

In the long-run, as RUK activity rises as a result of increased interregional exports to Scotland, labour demand rises in the RUK in the Wage Spillover (1) set-up (Figure D.10). Bargaining subsequently increases the real and nominal RUK wage, increasing the linked Scottish nominal wage. The indirect nature of the effect means that nominal wages increase by only 0.08% over base in this scenario in the period immediately following the shock, compared with an increase of 0.34% in the Quasi I-O case, where real wages remain fixed at the regional level. Consequently, in the Wage Spillover scenario, the Scottish real wage initially falls (Figure D.4), since the percentage increase in the RUK nominal wage is less than the percentage increase in the Scottish CPI. The initial relative fall in Scottish real wages, and the accompanying smaller increase in nominal wages compared with the other model configurations, accounts for the rapid initial expansion in Scottish GDP in this model set-up relative to the other scenarios (Figure D.1). In Period 3, GDP is 0.55% higher than base in the Wage Spillover (1) scenario, compared with 0.44% for the Quasi I-O closure. In the long-run, however, there is some increase in the Scottish real wage, brought about by the stimulus to RUK economic activity. This explains the slightly lower long-run GDP increase over base relative to the Quasi I-O configuration.

The introduction of migration has a limited effect on overall activity in Scotland. The adjustment paths of GDP, employment and exports for both Wage Spillover scenarios are in close accord for the duration of the simulation period. In the Wage Spillover (2) configuration there are, however, significant changes in the size of the population. Following the demand stimulus, as employment rises in Scotland, the population migrates inward from the RUK. Unlike in the Bargaining scenario, regional real wages are not directly linked to the tightness of the regional labour market in Scotland. However, the introduction of migration does still have an impact on wages in Scotland. Scottish in-migration and the tightening of the RUK labour market have consequences for nominal wages in the RUK, and therefore in Scotland too, though the effect is small. Exports to the RUK increase by less under the Wage Spillover configuration with migration (Figure D.7), reflecting weaker RUK activity in this case (see Section 4.1.8).

Table 3.6 Wage Spillover (2) summary results

	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	£346.26m	£-34.25m	£623.67m	£-202.19%	£841.47m	£-483.67m
	0.55%	-0.01%	1.00%	-0.03%	1.34%	-0.07%
Total employment	12,784	-1,945	18,946	7,906	23,895	-15,043
	0.67%	-0.01%	1.00%	-0.04%	1.26%	-0.07%
Traded sector employment	0.84%	-0.01%	1.27%	-0.04%	1.61%	-0.08%
Sheltered sector employment	0.30%	-0.02%	0.40%	-0.04%	0.50%	-0.06%
CPI	0.29%	0.08%	0.21%	0.08%	0.10%	0.10%
Commodity output prices	0.40%	0.08%	0.26%	0.09%	0.13%	0.11%
Price of value added	0.60%	0.08%	0.35%	0.10%	0.14%	0.13%
Nominal wage	0.10%	0.10%	0.14%	0.14%	0.16%	0.16%
Real wage	-0.19%	0.02%	-0.07%	0.06%	0.06%	0.06%
Exports to the other region	-0.9%	1.27%	-0.43%	1.47%	-0.11%	1.55%
Exports to ROW	3.76%	-0.16%	4.38%	-0.17%	4.69%	-0.21%
Population	15,699	-15,699	41,936	-41,936	61,905	-61,905

4.1.8 Wage Spillover (1) and (2): RUK economy results

In contrast to the Scottish economy results, the two Wage Spillover configurations generate significantly different results for the RUK economy depending on whether migration is included in the set-up (Figure D.8). In the Wage Spillover (1) scenario, GDP is 0.03% above base by the end of the simulation period, compared with a 0.07% fall in GDP in the Wage Spillover (2) closure (Tables 3.5 and 3.6). Under both scenarios, RUK exports to Scotland increase, in response to a rise in demand for RUK intermediate inputs. The direct effects of the shock in the Scottish economy, however, mean that the fall in Scottish unemployment is greater than in the RUK (unemployment falls by 3.77% in Scotland compared with a fall of 0.26% in the RUK in period 3). Under the Wage Spillover (2) configuration, this encourages some of the labour supply to out-migrate from the RUK economy, and the resultant labour market constraints account for the significantly lower GDP trajectory in this scenario.

4.2 National economy results

Under all configurations, the policy shock leads to an increase in national GDP and employment relative to base, and for the duration of the simulation period (Figures D.15 and 16). In the long-run, the Quasi I-O case leads to the largest relative increase in national employment, with an increase of 44,358 relative to base in period 50 (Table 3.7). As in the case of the individual regions, the inflexibility of wages in this scenario means that the UK economy does not experience negative competitiveness effects generated through the labour market as employment rises, and this underlies the strength of the GDP results. The Wage Spillover (1) configuration provides the next best long-run improvement in employment relative to base, with an increase in employment of 28,109 by period 50. Although the national economy is population-constrained in this set-up, unlike in the Quasi I-O case, the increase in employment and corresponding increase in real wages is diluted as the effects feed through via the RUK economy, so the dampening effect of rising real wages on competitiveness is limited. In contrast, the responsiveness of wages and the associated deterioration in competitiveness in the Bargaining scenario results in this closure providing the third best relative increase in employment in the long-run. The presence of migration, and the corresponding capacity constraints for the RUK economy, means that the Wage Spillover (2) and Flow Migration configurations provide the two weakest long-run increases in national employment, despite these closures resulting in significant increases in Scottish employment relative to base.

These are surprising results: intuitively, we would suggest that regional migration restrictions and wage rigidity would create distortions in the national market, giving rise to a misallocation of resources amongst regions. So we would expect that those scenarios incorporating wage flexibility and no barriers to migration would generate higher increases in employment and activity relative to scenarios that do not allow for either or both of these features[21]. But the reverse is true in this analysis: the most flexible labour market scenario, the Flow Migration case, yields the second lowest national economic performance in terms of output and employment. The other model set-up to include migration, the Wage Spillover (2) configuration, provides the lowest outcome. The explanation for these finding are embodied within the initial SAM data, which are assumed to represent an equilibrium position. The equilibrium unemployment rate in Scotland is higher than that in the RUK - which we take to represent the presence of a compensating amenity value attached to living in the target region. Employee productivity is also lower in Scotland. Thus the Flow Migration and Wage Spillover (2) equilibria require the population to shift from a higher to a lower per capita productivity region, and following the shift, the migrants, despite feeling better off overall, take on the productivity and unemployment characteristics of the population in Scotland[22].

Incorporating some degree of wage flexibility also reduces the positive impact of the shock on the national economy, contrary to expectations: the Quasi I-O set-up, with fixed real wages, results in the strongest long-run national employment and output performance overall. In this analysis, it is the open-economy assumption that drives this result, since the export market is rendered less competitive in those scenarios with flexible wages. The strong performance of the Quasi I-O scenario is less surprising in consideration of the complete lack of population constraints in this set-up.

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[21] Labour market flexibility continues to be one of the key issues of global labour market reform, and there exists an extensive literature on the effects of labour market flexibility on economic activity, though much of the focus has been on regulatory reform. Studies that focus on the responsiveness of wages to labour market conditions and the associated impact on economic efficiency include Faggio and Nickell (2005) and Millard (2000). Research that considers the gains from the elimination of global migration barriers include Iregui (2005) and Moses and Letnes (2004), and in an interregional context Archibald (1969).

[22] Partridge and Rickman (1997, 2003) consider that higher regional amenity levels can serve as compensating differentials for higher regional unemployment rates. In this analysis, although national economic performance is lowest for the configuration incorporating migration, unless the amenity value of Scotland is reduced by the in-migration, there is not a negative national effect in terms of welfare/utility.

In the years immediately following the shock, however, it is the Wage Spillover (1) and (2) closures that lead to the best outcome for the UK economy in terms of the relative increase in employment. In period 2, employment is 11,904 and 10,585 higher than base, respectively. This compares with an increase of 9,407 for the Quasi I-O scenario (Figure D.16). The rapid initial expansion in national employment is attributable to the significant increase in Scottish employment, which itself arises because of the fall in real wages in the short-run. In the absence of migration, the Wage Spillover (1) case continues to out-perform that of the Quasi I-O scenario until period 7. In the presence of migration, labour market displacement effects mean that the Quasi I-O case outperforms the Wage Spillover (2) case by period 3.

Table 3.7 National economy summary results

		Period 3	Period 10	Period 50
Change in National GDP	QUASI IO	£319.87m (0.04%)	£749.58m (0.09%)	£1574.10m (0.02%)
	BARGAINING	£197.66m (0.03%)	£373.91m (0.05%)	£483.91m (0.06%)
	FLOW MIGRATION	£189.07m (0.02%)	£331.84m (0.04%)	£361.65m (0.05%)
	WAGE SPILLOVER (1)	£377.99m (0.05%)	£730.75m (0.09%)	£1026.01m (0.13%)
	WAGE SPILLOVER (2)	£312.02m (0.04%)	£421.48m (0.05%)	£357.79m (0.05%)
Absolute Change in National Employment	QUASI IO	11,360	22,576	44,358
	BARGAINING	6,265	9,428	11,468
	FLOW MIGRATION	5,947	8,273	8,889
	WAGE SPILLOVER (1)	13,624	21,568	28,109
	WAGE SPILLOVER (2)	10,803	11,040	8,852

5. Policy discussion and conclusions

In a UK context, research into regional policy impacts has focused almost wholly on the effects of the policy on the target region, with any consequences for other regions being largely ignored (Taylor, 2002). The results reported here suggest that regional policy spillovers may be significant, even when the target region is small relative to the national economy. Under all model scenarios, an increase in Scottish trade - which is the desired and anticipated response to some aspects of Scottish government policy - results in a positive stimulus for the Scottish economy. The configuration of the regional labour market and migratory behaviour appear to be important factors in determining the magnitude of the stimulus and the adjustment path of the economy. In each model set-up, spillover effects do arise for the RUK, with obvious consequences for national effects, and the labour market characteristics are also important in determining the overall national outcome.

The incorporation of both a time element and non-target region effects into the study highlights some important policy issues. Firstly, the results suggest that the move to long-run equilibrium is generally slow. The time horizon for the evaluation of local regeneration policy is a ten year maximum (HM Treasury, 1995), but significant adjustments occur beyond this time period in both the Scottish and RUK economies. GDP is not close to its long-run equilibrium until around period 25 for the Scottish economy, and longer for some of the RUK scenarios. Within the Treasury's ten-year evaluation period, the extent of the policy responses is much smaller than in long-run equilibrium, and this could prove misleading from a policy perspective.

Furthermore, both the size and the direction of the results can differ in each region, depending on the labour market scenario. The benchmark scenario, the Quasi I-O configuration, results in the highest increase in GDP for both regions during the whole of the simulation period. This is expected, given the absence of a national population constraint, or other restrictions on expansion in the long-run. However, the introduction of more realistic labour market characteristics leads to a significant variation in the results across the regions. In particular, the Flow Migration scenario leads to a long-run expansion in GDP in Scotland, but a contraction in the RUK. Thus policy makers focusing on the effects in the target region only would view this policy scenario as having a more positive long-run effect than they would do than if the national effects of the stimulus were to be taken into account. Similarly, policy makers who focus only on the target-region effects of the policy under the Bargaining scenario would have a misleading impression about the overall impact of the policy shock, since the target-region effects are an ‘under-estimation’ of the national effects. This matters not because the ranking of results for each of the scenarios is of interest, but because it implies that: (i) the overall outcome of a regional policy change depends on other-region effects, which themselves are sensitive to the macroeconomic structure of the economy; and (ii) the regional effects are not necessarily a good indicator of the national policy impact.

I analyse the interregional effects of the policy shock within a period-by-period framework, and I find that this also highlights a number of important points. The relative effects of the shock differ for the two regions in terms of both the timing and the size of the effects. The RUK economy takes longer to adjust to the shock, due to the constraints imposed on the transmission mechanism by the presence of active supply-side effects. In some cases, the results differ markedly between the ten-year and fifty-year results, depending on the characteristics of the labour market. This suggests that a longer evaluation period than the Treasury’s current ten-year timescale may be required for policy decision-making.

These various issues have obvious effects on the aggregate impact of the shock for the national economy, and ultimately on appropriate policy responses. These are insights that would not be revealed if policy makers were to focus only on the target-region effects of regional policy, or on long-run equilibrium outcomes. Overall, the results reinforce policy makers’ movement away from assuming zero national effects of regional policy. This study goes further to fully reject the notion of complete crowding out, even in the case of a demand disturbance. This has significant consequences for current policy design and evaluation methods, since the size and direction of the other-region effects can no longer be accurately measured a priori. If the national effects of regional policy are not presumed to be zero, then an essential component of the policy evaluation process ought to be the measurement of both target and non-target region impacts. Such a comprehensive analysis of the subject requires more detailed modelling techniques – of the kind employed in this study - that identify the national and interregional effects of government policies. Within this, the direction of the effects and an appreciation of the absolute and relative scale of the effects are important.

Despite this, the Treasury's previous doubt over the net benefits of regional policy appears to remain embedded in the current decision making process. In practice, the Treasury provides no guidance on how to measure spillover effects. Nor has it commented on the size or timing of potential spillovers. At present, there is no evidence of the Treasury adopting an evaluation approach that is in line with its apparent shift away from the assumption of full crowding out. Continued implementation of the current evaluation process could potentially encourage an overall implicit bias against regional policy, in that it may lead to an underestimation of the net benefits associated with such policies.

A number of extensions could potentially add value to the research of this Chapter. At present, data constraints limit the analysis in this chapter to a two-region, three sector framework. However, a more disaggregated framework - which necessitates the publication of more timely and consistent official regional and national I-O tables - would allow for more detailed consideration of precise policy measures. In Chapter 6, I conduct a more sectorally-disaggregated analysis of a more specific demand-side stimulus: the development of a domestic and export market for UK-manufactured tidal energy devices. I use a national CGE framework to do so, and the findings of this chapter prove to be informative in deducing the types of interregional effects that may underlie the national results.

Additionally, it may be useful to consider the public sector cost implications associated with the export stimulus. At the outset of this Chapter I suggest that the export demand shock could arise, for example, as a costless consequence of international obligations to increase the share of energy consumption derived from renewable energy sources. In practice, however, costly policy measures may be required to support the development of an export market for the Scottish renewable energy sector. These could include, for example, capital expenditure grants for manufacturers, or public sector investment in an offshore energy transmission structure. An informative exercise could therefore be to combine a regional export stimulus with an increase in public expenditure that is paid for through higher taxation at the national level. Furthermore, sensitivity analysis of alternative key parameter values and functional forms in addition to the labour market scenarios that are considered could be beneficial. These and other possibilities for future research are discussed further in Chapter 7.

Chapter 4[1]

Regional Policy Spillovers: Evaluating the National Impact of Supply-Side Policy in an Interregional Computable General Equilibrium Model of the UK

1. Introduction

This chapter considers the net national impact of a policy-induced regional supply shock, using an interregional CGE model of the UK economy. The motive underlying this research is closely related to the focus of the previous chapter. In the UK, the assessment of regional policy has focused primarily on the impacts within the target region, with national and non-target region effects being largely ignored. A considerable literature examines the consequences of local development policy on the target region (Taylor, 2002; Wren, 2003), but studies that evaluate spillover effects on other regions are rare. Similarly, UK regional policy-making does not appear to have been influenced by the potential for spillovers in practice. This is the case even for supply-side policies, despite the Treasury having explicitly acknowledged that supply-side disturbances can have a net national impact (HM Treasury, 2003). The contribution of this chapter is to provide a more comprehensive assessment of the impact of a policy-induced regional shock, which in this case emanates from supply-side factors.

In this chapter, I use the two-region AMOSRUK framework used in Chapter 3, in order to analyse the full spatial impact of a policy-induced supply-side stimulus. As discussed in Chapter 3, the CGE methodology provides a more complete assessment of the impact of regional policy than previous research has allowed. Firstly, the model identifies the nature and extent of interregional linkages in the UK economy, which enables me to focus on the non-target and national impact of the policy change. The national constraints within which the system of regional economies operates will play an important role in determining the spatial outcome of a policy disturbance, and

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[1] The analysis of this chapter has been submitted in part to the Journal of Regional Science, and is currently at the 'revise and resubmit' stage.

the flexibility of the model structure allows me to investigate this issue, this time from a supply-side perspective. I specify alternative assumptions for wage-setting and migration behaviour at the regional and national level, with the objective of determining the importance of these national constraints in influencing the spatial impact of the supply-side policy change.

Secondly, the CGE framework allows me to incorporate a time element into the study. Thus I can identify the short- and long-run adjustment paths of the economies in response to the shock, and consider whether there are any significant economic adjustments that occur outwith the Treasury's ten year evaluation period for regional policies. Each of these contributions is comparable to those of the demand-side analysis of the previous chapter. In this chapter, however, I find that the supply-side nature of the stimulus results in economic consequences for both the regional and national economies which are quite distinct from those of the demand-side study. Features of the CGE framework help to reveal the different adjustment processes at work.

The research updates and extends previous regional policy analyses carried out with the AMOS and AMOSRUK models in a number of ways. Gillespie et al. (2001a, 2001b) each explore the impact of a demand-side stimulus related to local development initiatives, though in the context of a single region model of the Scottish economy only. McGregor et al. (1999) and Gillespie et al. (2002) each conduct interregional policy analyses using the AMOSRUK model. In McGregor et al. (1999), the authors investigate the effects of a regional demand-side shock, though the analysis is restricted to long-run simulations only. The simulations in this chapter are most comparable to that of Gillespie et al. (2002), since the authors also examine the impact of a supply-side shock within an interregional model of the UK economy, though key elements of the research differ. Gillespie et al. (2002) considers a factor-augmenting (Hicks-neutral) efficiency shock, incorporating the notion of policy decay, whereas this paper investigates the effects of a one-off step increase in labour efficiency, with no policy decay. Gillespie et al. (2002) incorporates only one labour market closure, whilst in this chapter, I extend the analysis by considering the spatial impact of the policy change under a range of assumptions regarding the operation of the national and regional labour markets. In Chapter 3, I find that both the target and non-target regions are sensitive to this assumption, and the aim here is to consider whether this is similarly important for policy-making in the context of a supply-side stimulus. Furthermore, in this chapter I use an updated SAM database compared with the earlier research (1999 compared with 1989), and incorporate a longer time period of evaluation (a fifty-year simulation period, compared to the ten-year period in Gillespie et al., 2002). Consideration of a longer, period-by-period simulation time path is also potentially very relevant for supply-side policy analysis. In the previous chapter I find that a demand-side policy change can have significant impacts beyond the Treasury's ten-year evaluation time horizon, and that there are differences in the short-run versus long-run impacts, and also in the relative adjustment processes of the regional economies over time. In this chapter I find that for some of the simulations not only does the magnitude of the impact differ outwith the ten-year simulation period, but so too does the direction of the effects.

The type of policy change that I consider relates closely to the direct impact expected from one of the policy priorities identified by the Scottish government. Increasing labour productivity has been identified as a key objective of the Scottish 'Government Economic Strategy' (Scottish Government, 2007a)[2]. In this paper, I explore the consequences of a successful policy designed to increase productivity, though I do not explicitly consider the policies that could potentially achieve this effect[3]. Nor do I consider the cost of such policies. For simplicity, I assume that the policy shock is achieved via an increase in the efficiency of existing policies.

The remaining discussion is structured as follows. The reader is referred to Appendix A for the AMOSRUK model listing and Appendix B for a description of

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[2] The report identifies that Scottish productivity rates are low by international standards and relative to the UK as a whole, and acknowledges that sustainable increases in the rate of growth of productivity will be achieved through, among other means, a more highly skilled and knowledgeable labour force.

[3] The model employed here does not explicitly incorporate labour disaggregated by skill. I consider the effects of an increase in labour market efficiency across all skill levels of the Scottish traded sectors.

the labour market scenarios used in the simulations. The model and its labour market configurations are identical to those used in Chapter 3 and so, for the sake of brevity, are not repeated here. In Section 2 I report the results of the model simulations and in Section 3 I discuss the policy implications of the results and provide concluding comments. Tables summarising the changes to key economic variables for each labour market configuration are provided within the text. The results figures are referred to at various points within the text, and so are presented together in Appendix E for ease of reference.

2. Simulation results

This analysis considers the system-wide effects on Scotland and the RUK of an increase in labour efficiency in the Scottish traded sectors. I assume that the policy is ‘costless’, in that it does not invoke an offsetting impact elsewhere in the economy. The simulation method involves a 5% step increase in Harrod-neutral (labour-augmenting) technological progress in the target region traded sectors (i.e. the Scottish manufacturing and non-manufacturing traded sectors). The model is run forward for 50 periods with the values of all other exogenous variables held constant, and the changes from the initial base-period value are reported for the key variables. In all cases, capital stock is updated between periods, and in the Flow Migration configuration the regional populations are adjusted in a similar manner. In the other scenarios, the regional populations remain constant.

The model calibration process takes the economy to be initially in long-run equilibrium. This means that if the model is run forward with unchanged exogenous variables and parameters, the endogenous variables continuously take their initial values. Introducing a step change drives the economy towards a new long-run equilibrium and it is the paths to the new comparative static equilibria that are reported here. The different model configurations generate both different long-run equilibria and different adjustment paths.

The simulation results are discussed for each model configuration in turn. The long-run versus short-run impacts are discussed, along with the relative effects in each region. Figures E.1 – E.16 in Appendix E show the trajectories for the change in key variables relative to base for the five model configurations. Figures E.1 – E.7 relate to the Scottish economy; Figures E.8 – E.16 to the RUK economy. Within the main text, Tables 4.1 – 4.6 summarise the results for key variables. Aggregate economic variables are reported in both absolute and percentage terms; the remaining key variables are reported in percentage terms. Some key variables (such as capital rental rates and commodity output prices) do vary across the three sectors, but in some instances, to aid clarity, a weighted average of the change across all sectors is presented. Each variable is expressed in terms of its change (absolute or percentage) relative to base.

2.1 Regional economy results

2.1.1 Quasi I-O: Scottish economy results

Following a positive labour efficiency shock in the Scottish economy, wages per efficiency unit of labour fall in the traded sectors, as do the prices of value-added and commodity outputs in these sectors. By period 50, the prices of value-added and commodity outputs in the traded sectors are 2.72% and 2.06% lower than base period values, respectively (Table 4.1).

In the long-run, these price effects feed through to the wider economy: even those sectors that did not experience the shock first-hand face downward price pressures. These other sectors face cheaper intermediate inputs to production, so economy-wide output prices fall over time. This results in a downward trajectory for prices over the period: CPI is 1.75% below the base value by period 50 (Figure E.1). This means that nominal wages fall across all Scottish sectors (Figure E.2), further reinforcing the decline in commodity prices, though real wages remain fixed in this scenario (Figure E.3).

Table 4.1 Quasi I-O summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	1.84%	0.03%	3.15%	0.08%	4.89%	0.25%
	£1153.5m	£182.9m	1971.0m	£537.4m	£3062.6m	£1767.4m
Total employment	-0.78%	0.03%	0.30%	0.08%	1.75%	0.25%
	-14,820	6,899	5,614	17,371	33,139	50,777
Traded sector employment	-1.56%	0.04%	-0.23%	0.09%	1.57%	0.28%
Sheltered sector employment	0.95%	0.02%	1.49%	0.05%	2.24%	0.14%
CPI	-0.59%	-0.05%	-1.07%	-0.10%	-1.75%	-0.25%
Commodity output prices	-0.64%	-0.03%	-1.24%	-0.08%	-2.06%	-0.22%
Traded sector commodity output prices	-1.06%	-0.03%	-1.83%	-0.08%	-2.88%	-0.23%
Price of value added	-0.89%	-0.03%	-1.67%	-0.08%	-2.72%	-0.22%
Traded sector price of value added	-1.54%	-0.02%	-2.61%	-0.06%	-4.01%	-0.21%
Nominal wage	-0.59%	-0.05%	-1.07%	-0.10%	-1.75%	-0.25%
Real wage	0.00%	0.00%	0.00%	-0.01%	0.00%	0.00%
Exports to the other region	1.52%	0.41%	2.67%	0.64%	4.24%	1.00%
Exports to ROW	1.65%	0.07%	3.04%	0.17%	4.98%	0.45%

The price effects provide a long-run competitiveness boost for the Scottish economy: interregional and ROW exports increase (Figures E.4 and E.5 respectively), especially so in the traded sectors, where the price effects are most significant due to the direct effects of the shock. Exports to the RUK increase due to cheaper commodity output prices in Scotland relative to the RUK and higher consumption demand in the RUK. The increase in exports to the ROW is also attributable to the fall in Scottish commodity output prices, but there are additional factors at work that contribute to the stronger increase in exports to the ROW relative to that of the RUK. Firstly, the efficiency shock creates a larger relative price advantage for Scottish exports to the ROW than for Scottish exports to the RUK. As commodity output prices fall in Scotland, so too do prices in the RUK, via the effects of cheaper intermediate inputs. The Scottish economy still experiences a price advantage over the RUK, due to the direct effects of the efficiency shock, but the exogeneity of the ROW – and a corresponding zero change in ROW prices – means that the relative price advantage that Scotland experiences with the ROW is more pronounced.

Secondly, lower nominal wages mean that there is an additional competitiveness boost to Scotland's external trade.

Overall, the reduction in prices and nominal wages that stems from the productivity shock provides a long-run stimulus to Scottish GDP (Figure E.6). Total output increases by 4.89% by period 50, relative to base. The quantity of traded sector commodity outputs increases by 5.46% by this period relative to base; sheltered sector outputs by 2.10%. In line with this output expansion, employment rises above its benchmark equilibrium in the long-run (Figure E.7). Traded sector employment is 1.57% above its base rate in period 50; sheltered sector employment is 2.24% higher.

In the initial periods following the shock, however, employment falls in Scotland (Figure E.7). This is due to two effects. Firstly, fewer labour inputs are required in the traded sector production process due to the efficiency shock. Secondly, the positive output effects resulting from lower prices and wages and higher competitiveness that work to counteract falling labour demand, take time to feed through due to capacity constraints. The direct effects of the efficiency boost result in traded sector employment being 2.1% (27,270) lower than base in the first period following the shock. This compares with a 0.7% increase (4,300) in employment in the sheltered sector - where the efficiency shock is not directly levied - relative to base for the same period. Over time, however, investment adjusts capital stocks and capacity constraints relax, allowing the economy to take fuller advantage of the competitiveness boost, and the increase in overall long-run GDP relative to base in this case is the strongest of all the scenarios considered in this paper (Figure E.6).

Although the efficiency stimulus leads to an overall increase in short-run output - due to the improvement in Scottish competitiveness - the accompanying short-run fall in employment presents a conflict for policy appraisal and evaluation purposes. Examining the effects of the shock within a framework that allows for period-by-period analysis highlights an important limitation of the Treasury's ten-year maximum time period for the evaluation of local development policy. For much of this evaluation period, employment is lower relative to base, despite the increase in GDP, and despite long-run increases in output and employment. This is true across all the model scenarios[4].

2.1.2 Quasi I-O: RUK economy results

The RUK economy also experiences a positive stimulus to long-run economic activity following the efficiency shock in Scotland. In the RUK, too, the source of the expansion is a reduction in economy-wide prices and an increase in external competitiveness.

Close interregional trade linkages between Scotland and the RUK mean that cheaper intermediate inputs from Scotland lead to lower commodity output prices in the RUK across all sectors in the long-run. In period 50, commodity output prices are 0.22% lower compared with the base value, and overall CPI is 0.25% lower. This fall in prices, combined with fixed real wages in this scenario, means that nominal wages fall 0.25% below the base value by period 50. These wage and price effects together provide a positive boost to RUK trade to the ROW: exports to the ROW are 0.45% higher than base by period 50. Further, RUK exports to Scotland are 1.00% higher than base by the end of the simulation period, reflecting stronger activity in the Scottish economy. These improvements to export demand (Figures E.11 and E.12) act as the main driver behind an upward GDP trajectory for the RUK, compared with the benchmark equilibrium (Figure E.13).

The magnitude of the overall effects in the Scottish and the RUK economies differs significantly in percentage terms. Whilst in Scotland the efficiency shock leads to a 4.89% increase in GDP relative to base in the long-run, the comparative figure for the RUK is just 0.25%. This is explained by the differing composition of each region's export market. Whilst exports to the RUK account for around 50% of Scotland's total exports, exports to Scotland constitute only around 13% of the

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[4] Employment ultimately increases relative to base for all the labour market scenarios, though the increase in the two Wage Spillover cases is minimal (see Section 2.1.7).

RUK's total exports. The relatively small share of the RUK's other-region exports means that the RUK has fairly limited exposure to the positive effects of the efficiency stimulus that feeds through from the Scottish economy. In terms of the absolute magnitudes of the simulation effects, the results are much closer (Figures E.6 and E.13). Despite the Scottish economy being relatively small compared with the RUK, trade linkages mean that spillover effects are nonetheless significant and positive.

Although the overall impact of the Scottish efficiency shock is an increase in long-run GDP in both regions for this model scenario, the effects of the stimulus are much slower to materialise in the RUK. In period 3, the relative increase in GDP is almost 38% of its long-run period 50 value. In contrast, RUK GDP in period 3 is just over 10% of its long-run value (Table 4.1). The sources of the stimulus differ across the regions and this, together with the contribution of the transmission mechanism, makes for a delayed adjustment in the RUK economy.

In Scotland, the improvement in traded sector competitiveness brings about an increase in ROW demand for Scottish exports. The increase in labour efficiency means that labour market constraints are relaxed in this sector. In the absence of an improvement in labour efficiency in the sheltered sector, however, the short-run change in sheltered sector commodity output prices is small relative to the decreases in commodity output prices in the traded sector. Furthermore, since capital stocks are fixed in the short-run, the whole economy experiences capacity constraints to some degree in the periods immediately following the shock. Over time, as investment adjusts capital stocks, and commodity output prices fall to a greater extent, the full effects feed through to the Scottish economy.

In the RUK, the source of the delayed response of GDP is the relatively slower increase in RUK exports to the ROW, compared with that of Scotland. In period 3, the increase in RUK exports to the ROW is just over 15% of its long-run increase, compared with a figure of nearly 38% for Scotland. On the other hand, the adjustment speed for other region exports is very similar in Scotland and the RUK.

In period 3 the increase in RUK exports to Scotland is around 44% of its long-run value, compared with an equivalent figure for Scotland's exports to the RUK of around 40%. Only when capital constraints fully adjust in Scotland are the entire effects of the reduction in Scottish commodity output prices passed on to the RUK economy via cheaper intermediate input prices. Whilst the Scottish economy receives an immediate demand injection to the traded sector following the efficiency shock and the associated improvement in competitiveness, it is the effects of cheaper intermediate input prices from Scotland which bring about improved external competitiveness in the RUK, and these indirect effects take time to feed through.

The results for the RUK labour market also illustrate the differing extent of the effects in each region. Total employment is 0.25% higher than base for the RUK by period 50, relative to an increase of 1.75% for the Scottish economy. Furthermore, the adjustment paths of the regional labour markets diverge: whilst total employment falls in Scotland in the short-run as a result of the efficiency shock - owing to there being fewer labour inputs required in the production process - the same is not true for the RUK. Since there is no increase in labour efficiency in the RUK economy, the changes in employment stem only from positive competitiveness effects and the resulting increase in export demand. In contrast to that of Scotland, RUK total employment increases throughout the simulation period for this set-up, relative to base. Traded sector employment rises by most (0.28% relative to 0.14% for the sheltered sector), reflecting that this sector would be most exposed to changes in the price of intermediate inputs from the Scottish traded sector, and thus most susceptible to the competitiveness boost that cheaper intermediate inputs from Scotland brings about.

2.1.3 Regional Bargaining: Scottish economy results

Within the Bargaining configuration, similar effects work through the Scottish economy as in the previous Quasi I-O scenario: wages per efficiency unit of labour fall, and this puts downward pressure on prices in the traded sectors, and also in the wider economy via cheaper intermediate inputs for non-traded sectors. In this scenario, however, the responsiveness of long-run real wages works to dampen the competitiveness boost that occurs as a result of lower prices. The stimulus to long-run economic activity is therefore significantly lower under the Bargaining scenario relative to the previous configuration, where real wages remain fixed (Figure E.6).

In the long-run, as output expands and unemployment falls in response to the efficiency shock, real wages are bid up via Equation (4.1), so that by period 50, real wages are 0.73% higher relative to base (Figure E.3). With rising real wages, economy-wide prices fall by less in the long-run in this scenario relative to the previous one. CPI is 1.32% lower than its base value in period 50; this compares with a relative reduction of 1.75% in the Quasi I-O scenario. Less significant long-run relative decreases in the prices of value added and commodity outputs in the traded sector (-3.21 % and -2.28% respectively, compared with -4.01% and -2.88% in the Quasi I-O case) mean that downward price pressures still feed through to the other sectors via cheaper intermediate input prices, but that the effect on economy-wide prices is more subdued. Furthermore, the fall in CPI, combined with a rise in real wages, results in nominal wages falling by less in this set-up (-0.6%) by period 50 compared with the Quasi I-O scenario (-1.75%) (Figure E.2). Although the fall in CPI and nominal wages does improve competitiveness, the increase in interregional and international trade is also less significant than in the previous scenario (Figures E.4 and E.5). By the end of the simulation period, exports to the RUK and the ROW increase by 3.16% and 3.51% respectively, relative to base. The equivalent Quasi I-O relative increases are 4.24% and 4.98%. Thus the overall impact of the efficiency stimulus is a relative increase in long-run Scottish GDP, but the effect is less strong than under the previous scenario (Figure E.6). GDP increases by 3.75% over base by the end of the simulation period in this scenario, compared with 4.89% for the Quasi I-O case.

However, in the shorter run, and in contrast to the Quasi I-O case, the competitiveness effect is actually reinforced with the bargained real wage closure. Following the efficiency shock, employment falls relative to base for around 7 periods in both the Bargaining and Quasi I-O cases (Figure E.7): fewer labour inputs are required in the production process, and capacity constraints mean that positive output effects do not initially feed through to outweigh these effects. In the Bargaining case, falling employment in the short-run leads to a fall in real wages, whilst, in contrast, real wages remain unchanged in the Quasi I-O configuration (Figure E.3). This, in turn, leads to a larger relative reduction in the nominal wage (-1.19% in period 3) compared with the previous scenario (-0.59%) (Figure E.2). The additional stimulus creates a higher increase in GDP in the short-run under the Bargaining scenario (2.14% in period 3) relative to the Quasi I-O scenario (1.84% in period 3) (Figure E.6). The responsiveness of the real wage in the Bargaining scenario means that the reverse is true over time: after period 7, employment rises in both scenarios, but real wages rise only under the Bargaining case, resulting in a more subdued boost to output relative to the Quasi I-O scenario during the remainder of the simulation period.

Table 4.2 Bargaining summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	2.14%	0.01%	3.16%	0.03%	3.75%	0.05%
	£1339.9m	£87.8m	£1979.5m	£205.2m	£2349.9m	£319.9m
Total employment	-0.40%	0.02%	0.24%	0.03%	0.61%	0.04%
	-7,507	3,055	4,555	5,928	11,431	8,410
Traded sector employment	-1.15%	0.02%	-0.27%	0.03%	0.25%	0.05%
Sheltered sector employment	1.28%	0.00%	1.40%	0.00%	1.46%	0.01%
CPI	-0.68%	-0.05%	-1.07%	-0.08%	-1.32%	-0.11%
Commodity output prices	-0.92%	-0.03%	-1.17%	-0.05%	-1.31%	-0.06%
Traded sector commodity output prices	-1.17%	-0.04%	-1.86%	-0.06%	-2.28%	-0.08%
Price of value added	-1.26%	-0.02%	-1.59%	-0.03%	-1.76%	-0.04%
Traded sector price of value added	-1.71%	-0.01%	-2.65%	-0.03%	-3.21%	-0.05%
Nominal wage	-1.19%	-0.03%	-0.84%	-0.03%	-0.60%	-0.04%
Real wage	-0.52%	0.03%	0.23%	0.05%	0.73%	0.07%
Exports to the other region	1.81%	0.39%	2.66%	0.63%	3.16%	0.75%
Exports to ROW	2.09%	0.07%	2.98%	0.11%	3.51%	0.14%

2.1.4 Regional Bargaining: RUK economy results

For the RUK economy, the efficiency shock in the Scottish traded sector generates a potential stimulus via cheaper intermediate input prices from Scotland, and increased demand for RUK exports from the Scottish economy. As in the Quasi I-O scenario, Scotland experiences a fall in economy-wide prices and an improvement in demand and competitiveness. The effects are therefore felt by the RUK economy - albeit to a weaker extent - as they filter through interregional trade linkages. Overall commodity prices fall in the RUK, but by less so than in Scotland, and this is reflected in a much weaker boost to RUK exports to the ROW relative to that of Scotland (Table 4.2).

In the Bargaining scenario, the long-run extent of the effects on Scottish prices, demand and competitiveness are weaker than under the Quasi I-O scenario, and this means that the impact on the RUK economy is further reduced as the effects feed though interregional linkages. By the end of the simulation period, RUK GDP is 0.05% higher than base in this scenario, compared with 0.25% in the previous case. This scenario results in a smaller long-run fall in RUK CPI relative to the previous case (-0.11% compared with -0.25%) and a less significant reduction in nominal wages (-0.04% compared with -0.25%). As a result of a weaker competitiveness boost, exports to the ROW increase by less in the long-run (0.14% compared with 0.45%). Furthermore, since the effect on Scottish demand is more subdued in the Bargaining case compared with the Quasi I-O case, RUK exports to Scotland also increase by less (0.75% compared with 1.00%).

In addition, the short-run competitiveness boost operating through the labour market that benefits the Scottish economy in this scenario does not materialise for the RUK. Since there is no direct efficiency shock in the RUK, there is no initial fall in employment due to less labour inputs being required in the production process (Figure E.14) and therefore no initial fall in real wages to boost short-run export demand (Figure E.10).

2.1.5 Flow Migration: Scottish economy results

As in the previous two scenarios, the efficiency shock also increases GDP relative to base when the potential for population migration is introduced into the model set-up (Figure E.6). The source of this long-run boost remains the same as in the previous Bargaining case: higher labour productivity reduces prices in the traded sectors and also in the wider economy via cheaper intermediate inputs. The resultant downward pressure on whole-economy prices boosts external competitiveness. In this case, however, the positive competitiveness effects are enhanced by in-migration.

In the previous Bargaining scenario, the results suggest that the presence of bargained real wages (in the absence of migration) dampens this competitiveness boost due to real wages being bid up and economy-wide price reductions therefore being smaller in Scotland. Thus the increase in GDP relative to base is somewhat weaker than in the Quasi I-O scenario, where real wages remain fixed. In the Flow Migration case, however, the presence of interregional migration works to limit this increase in real wages over time (Figure E.3). In the longer run, as employment and wages rise, labour supply flows in to Scotland from the RUK (Table 4.3) and eases regional labour market constraints to some extent, though there does remain a UK-wide labour market constraint (we assume zero net inmigration in the UK overall). By period 50, real wages are 0.15% higher in this scenario relative to base, compared with 0.73% higher in the Bargaining set-up. Overall commodity output prices therefore fall by more in this scenario than in the Bargaining case (-1.78% by period 50, compared with -1.31%), as do nominal wages (a fall of -1.41% compared with -0.60%). Thus the improvements in competitiveness vis-à-vis the RUK and the ROW are more pronounced in the Flow Migration set-up than in the Bargaining configuration. Exports to the RUK increase by 3.84% compared with 3.16%, and to the ROW by 4.42% compared with 3.51%. As a result, the long-run GDP increase under this scenario is greater than under the Bargaining scenario, but lower than under the Quasi I-O scenario, where the real wage increase is zero, and the competitiveness effect stronger (Figure E.6).

Table 4.3 Flow Migration summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	2.03%	0.03%	3.02%	0.05%	4.59%	-0.04%
	£1272.5m	£194.8m	£1889.7m	£336.9m	£2876.1m	£-300.3m
Total employment	-0.55%	0.04%	0.11%	0.05%	1.47%	-0.05%
	-10,481	7,520	2,001	9,516	27,694	-9,995
Traded sector employment	-1.31%	0.04%	-0.43%	0.05%	1.23%	-0.05%
Sheltered sector employment	1.13%	0.02%	1.32%	0.02%	2.07%	-0.06%
CPI	-0.66%	-0.05%	-1.03%	-0.09%	-1.55%	-0.08%
Commodity output prices	-0.83%	-0.04%	-1.10%	-0.06%	-1.78%	-0.02%
Traded sector commodity output prices	-1.15%	-0.04%	-1.79%	-0.07%	-2.64%	-0.05%
Price of value added	-1.13%	-0.01%	-1.49%	-0.05%	-2.40%	0.01%
Traded sector price of value added	-1.68%	-0.02%	-2.55%	-0.04%	-3.72%	0.00%
Nominal wage	-0.94%	-0.05%	-0.73%	-0.05%	-1.41%	0.04%
Real wage	-0.28%	-0.01%	0.30%	0.04%	0.15%	0.12%
Exports to the other region	1.74%	0.37%	2.54%	0.63%	3.84%	0.86%
Exports to ROW	1.95%	0.08%	2.82%	0.12%	4.42%	0.04%
Population	-22,080	22,080	-7,915	7,915	68,480	-68,480

The initial adjustments in the Scottish economy under the Flow Migration scenario highlight the economy-wide implications of interregional labour supply movements in the short-run relative to the long-run. Immediately following the shock, employment falls, as in the previous two scenarios (Figure E.7). Real wages therefore fall and commodity output and economy-wide prices fall (Figure E.1). In response to initial lower employment, higher unemployment and a corresponding fall in real wages (Figure E.3), some of the labour force moves to the RUK. In the short-run the labour market in Scotland is slacker due to the direct effect of the efficiency shock (Figure E.7). As the price effects work through to create a positive output stimulus, some of the labour supply migrates back to Scotland from the RUK. As employment continues to rise and unemployment falls, inward migration continues, and thus an overall increase in the labour supply eases regional labour market constraints in the long-run.

2.1.6 Flow Migration: RUK results

In contrast, the introduction of interregional migration makes for an overall relative reduction in long-run GDP for the RUK (Figure E.13). By the end of the simulation period, RUK GDP has fallen by 0.04% relative to base. This compares with a relative increase in GDP of 0.25% for the Quasi I-O scenario and 0.05% for the Bargaining closure. Both the Scottish and the RUK economies still experience falling prices and therefore an effective increase in competitiveness due to the efficiency shock, as in the previous two scenarios. Owing to the direct effects of the efficiency shock, however, the real wage increases and the increase in employment are ultimately stronger in Scotland relative to the RUK. These changes in the Scottish/RUK unemployment and real wage ratios imply that labour supply flows into the Scottish economy in the long-run from the RUK (Table 4.3), so that the RUK economy is unable to take full advantage of the competitiveness effects due to labour shortages. In period 50, the RUK population is 68,480 lower relative to base. RUK exports to the ROW are therefore more subdued in this scenario than in any of the other labour market configurations in the long-run (Figure E.12). In contrast, RUK exports to Scotland are comparatively strong (Figure E.11), attributable to the increase in economic activity in this region (Figure E.6).

The RUK economy does, however, experience a short-run increase in labour supply. In period 3, the RUK population is 22,080 higher relative to base, and the economy enjoys net inward migration for 12 periods following the efficiency shock. The initial increase in Scottish unemployment – owing to there being less units of labour required in the production process – means that Scottish real wages fall, and the population migrates towards the relatively more attractive conditions in the RUK labour market. During this period, the increase in GDP relative to base in the Flow Migration scenario outweighs that of the Bargaining configuration (Figure E.13), as the additional pool of labour supply allows the RUK economy to take fuller advantage of the competitiveness improvement that feeds through from the Scottish economy. The serious labour market constraints that occur in the longer run, however, mean that RUK GDP falls below base in the long-run (Figure E.13).

2.1.7 Wage Spillover (1) and (2): Scottish economy results

The Wage Spillover set-ups result in the weakest output stimulus for the Scottish economy: the Scottish GDP trajectories for both these scenarios are significantly lower than for the previous three configurations (Figure E.6), with GDP around 3.18% higher than base for both Wage Spillover scenarios at period 50, compared with a 4.89% increase under the Quasi I-O scenario (Tables 4.4 and 4.5). The source of the impact, albeit a weaker stimulus, is the same as in the previous model set-ups: as wage per efficiency unit of labour falls, lower commodity prices provide a competitiveness boost for the economy. The difference in these scenarios relative to the previous configurations is that the effects are somewhat more indirect and therefore less strong. In the Wage Spillover set-ups, it is the factors that determine the RUK nominal wage that determine the Scottish nominal wage, and thus the extent of the competitiveness effects and wider economic activity in Scotland. Following the shock, cheaper intermediate input prices from Scotland work to lower overall prices in the RUK. Lower RUK CPI lowers nominal wages in the RUK, and Scotland adopts this nominal wage. Because the Scottish economy is relatively small compared with the RUK, however, the effects on the RUK nominal wage are fairly limited, and thus the effects on the Scottish economy even more so. The overall effects on the Scottish economy are therefore much more diluted than in the alternative configurations. Scotland still gets the benefit of the reduction in commodity prices as a result of the efficiency gain, but not the associated wage effects that help to significantly boost activity in the three previous scenarios. In the Wage Spillover (1) and (2) scenarios, Scottish nominal wages fall only marginally, compared with the effects in the other scenarios (Figure E.2), and real wages rise (Figure E.3). Weaker competitiveness effects mean that the stimulus to exports, and overall activity, is subdued relative to the previous scenarios. In period 50, exports to the RUK and the ROW are 2.63% and 2.81% higher than base for both scenarios (Tables 4.4 and 4.5). This compares to equivalent relative increases of 4.24% and 4.98% for the Quasi I-O scenario.

Table 4.4 Wage Spillover (1) summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	1.59%	0.01%	2.46%	0.03%	3.18%	0.04%
	£995.1m	£86.2m	£1543.2m	£184.8m	£1989.0m	£299.8m
Total employment	-1.13%	0.02%	-0.49%	0.03%	0.03%	0.04%
	-21,285	3,051	-9,267	5,433	520	7,976
Traded sector employment	-1.92%	0.02%	-1.10%	0.03%	-0.42%	0.05%
Sheltered sector employment	0.64%	0.00%	0.88%	0.01%	1.07%	0.01%
CPI	-0.51%	-0.04%	-0.84%	-0.06%	-1.21%	-0.09%
Commodity output prices	-0.39%	-0.02%	-0.69%	-0.03%	-0.94%	-0.05%
Traded sector commodity output prices	-0.96%	-0.02%	-1.51%	-0.04%	-1.98%	-0.07%
Price of value added	-0.55%	-0.01%	-0.96%	-0.02%	-1.28%	-0.04%
Traded sector price of value added	-1.39%	-0.01%	-2.17%	-0.02%	-2.80%	-0.04%
Nominal wage	-0.02%	-0.02%	-0.03%	-0.02%	-0.03%	-0.03%
Real wage	0.49%	0.02%	0.82%	0.04%	1.10%	0.06%
Exports to the other region	1.26%	0.41%	2.01%	0.58%	2.63%	0.70%
Exports to ROW	1.26%	0.04%	2.10%	0.08%	2.81%	0.11%

The introduction of migration has a limited effect on the overall outcome. The adjustment paths of GDP, employment and exports for the Wage Spillover (1) and (2) scenarios are in close accord for the duration of the simulation period. In the Wage Spillover (2) configuration – where migratory behaviour is allowed for – there are, however, significant changes in the population. Following the efficiency shock, both unemployment and real wages rise in Scotland, but the unemployment effects outweigh the real wage effects such that some of the labour force migrates towards the RUK economy. The population deviation from base is most significant in period 5, when the population is 43,457 lower relative to its base value. Thereafter, in-migration to Scotland occurs, and the population returns to its base value by period 33, and rises marginally above base during the remaining simulation periods. Unlike in the previous Flow Migration scenario, the fall in population does not present serious capacity constraints: despite a lower labour supply, exports and GDP results for the Wage Spillover (2) scenario are very close to that of the Wage Spillover (1) scenario, where no population adjustment occurs. Since the price and competitiveness effects are more diluted in these scenarios relative to the Flow Migration case, the stimulus to economic activity is not strong enough to significantly tighten the labour market. The overall effect of the Wage Spillover (2) scenario is 'as if' the labour market is not tightening at all – there is sufficient capacity in the labour market to accommodate the change in activity.

Table 4.5 Wage Spillover (2) summary results

	Period 3		Period 10		Period 50	
	Scotland	RUK	Scotland	RUK	Scotland	RUK
GDP	1.59%	0.03%	2.47%	0.07%	3.18%	0.04%
	£997.1m	£236.1m	£1546.3m	£494.1m	£1988.6m	£281.3m
Total employment	-1.12%	0.05%	-0.49%	0.07%	-0.03%	0.04%
	-21,210	9,424	-9,160	14,877	507	7,355
Traded sector employment	-1.92%	0.05%	-1.09%	0.08%	-0.42%	0.04%
Sheltered sector employment	0.64%	0.03%	0.88%	0.04%	1.07%	0.01%
CPI	-0.53%	-0.04%	-0.86%	-0.08%	-1.12%	-0.09%
Commodity output prices	-0.43%	-0.03%	-0.73%	-0.06%	-0.94%	-0.05%
Traded sector commodity output prices	-0.99%	-0.03%	-1.54%	-0.07%	-1.98%	-0.07%
Price of value added	-0.60%	-0.03%	-1.00%	-0.06%	-1.28%	-0.03%
Traded sector price of value added	-1.44%	-0.01%	-2.20%	-0.05%	-2.80%	-0.04%
Nominal wage	-0.06%	-0.06%	-0.07%	-0.07%	-0.03%	-0.03%
Real wage	0.47%	-0.02%	0.80%	0.02%	1.10%	0.06%
Exports to the other region	1.32%	0.36%	2.06%	0.56%	2.62%	0.71%
Exports to ROW	1.32%	0.06%	2.17%	0.13%	2.81%	0.11%
Population	-35,159	35,159	-32,024	32,024	2,446	-2,446

2.1.8 Wage Spillover (1) and (2): RUK economy effects

In the RUK, under the Wage Spillover (1) and (2) scenarios, the stimulus works via the same channels as in the previous scenarios: cheaper intermediate inputs feed through from the Scottish economy and provide a competitiveness boost to the region relative to the ROW, and, further, there is a demand stimulus as a result of economic expansion in Scotland. In response to higher output and lower unemployment, real wages rise, resulting in a lower GDP trajectory than under the Quasi I-O scenario, where real wages remain fixed and the RUK stimulus to trade is most significant. Furthermore, because the effect on Scottish economic activity is relatively weak under these scenarios, the RUK economy does not benefit as greatly from the increase in Scottish demand for RUK exports. Of all the labour market configurations, the Wage Spillover scenarios provide the second-weakest long-run stimulus to RUK GDP, after the Flow Migration Scenario, where RUK GDP falls relative to base. Output is around 0.04% higher relative to base in period 50 for both Wage Spillover configurations. This compares to an equivalent figure of 0.25% for the Quasi I-O closure, which provides the highest GDP trajectory for the RUK economy.

In contrast to that of Scotland, the adjustment paths for the RUK economy under the Wage Spillover (1) and (2) scenarios differ significantly. In the periods following the shock, as labour demand falls in Scotland in the Wage Spillover (2) scenario, the RUK economy experiences net in-migration. The increase in labour supply helps to lower real and nominal wages, which therefore provides an additional external competitiveness stimulus. In period 3, nominal wages are 0.06% below base in Wage Spillover (2), compared with 0.02% below base in Wage Spillover (1), and exports to the ROW are relatively higher over the period (Figure E.12).

2.2 National economy results

For each of the model configurations, the policy shock leads to a long-run increase in national GDP and employment relative to base. The Quasi I-O case results in the largest relative expansion in overall UK economic performance in the long-run: GDP increases by £4,829.98m (0.71%) and employment by 83,920 (0.40%) by period 50 (Table 4.6). This is a significantly larger increase than occurs in the other scenarios (Figure E.15). The inflexibility of real wages means that as lower prices improve the competitiveness of exports and increase commodity outputs and the derived demand for labour, there is no associated increase in real wages to dampen the competitiveness effect. In the long-run, national nominal wages fall by most in this scenario, and ROW exports increase by most.

Table 4.6 National economy summary results

		Period 3	Period 10	Period 50
Change in National GDP (£m)	QUASI IO	1336.44 (0.21%)	2508.96 (0.38%)	4829.98 (0.71%)
	BARGAINING	1427.73 (0.22%)	2184.65 (0.34%)	2669.92 (0.42%)
	FLOW MIGRATION	1467.31 (0.23%)	2226.59 (0.34%)	2575.88 (0.42%)
	WAGE SPILLOVER (1)	1081.32 (0.17%)	1727.99 (0.27%)	2288.77 (0.36%)
	WAGE SPILLOVER (2)	1233.18 (0.19%)	2040.39 (0.31%)	2269.82 (0.35%)
Change in National Employment (000s)	QUASI IO	-7.92 (-0.05%)	22.99 (0.11%)	83.92 (0.40%)
	BARGAINING	-4.45 (-0.03%)	10.48 (0.05%)	19.84 (0.10%)
	FLOW MIGRATION	-2.96 (-0.02%)	11.52 (0.05%)	17.70 (0.10%)
	WAGE SPILLOVER (1)	-18.23 (-0.09%)	-3.83 (-0.03%)	8.50 (0.04%)
	WAGE SPILLOVER (2)	-11.78 (-0.07%)	5.72 (0.02%)	7.86 (0.04%)

The long-run GDP and employment performance of the national economy under the other four scenarios are all fairly close in value (Figures E.15 and E.16). The Bargaining scenario results in the next-best outcome for the national economy compared with the Quasi I-O case, with the reduced relative GDP increase attributable to rising wages and their corresponding negative impact on international competitiveness. GDP and employment increase by £2,669.92m (0.42%) and 19,840 (0.10%) respectively in this case. Contrary to expectations, the introduction of migration leads to a slight decrease in the GDP and employment impact relative to that of the Bargaining scenario. In the Flow Migration case in the long-run, GDP and employment increase by £2,575.88m (0.42%) and 17,700 (0.10%) respectively, with this slightly weaker performance related to the RUK supply constraints evident in this scenario (see Section 2.1.6). The long-run performance of the two Spillover scenarios are much the same: GDP and employment increase by £2,288.77m (0.36%) and 8,500 (0.04%) respectively in the Wage Spillover (1) case. This compares with relative increases £2,269.82 (0.35%) and 7,860 (0.04%) for the Wage Spillover (2) case. These scenarios result in the weakest long-run relative increase in national GDP and employment because the stimulus in the target economy - the main source of the national economic boost - is constrained due to the wage determination mechanism at work in these set-ups. The indirect way in which the policy affects nominal wages means that the overall impact on wages is significantly diluted, and so the Scottish economy does not benefit from lower wages and the corresponding increase in external competitiveness to the same extent as in the other scenarios. This, combined with the effects of wage bargaining at the RUK level – and the associated implications for RUK competitiveness – leads to a lower long-run GDP and employment outcome, compared with the other scenarios.

The presence of migration makes little difference to the long-run outcome: since the stimulus is largely suppressed in the target economy in these scenarios, the ability of the labour supply to move from areas of low to high capacity in order to ease labour supply constraints makes little difference, since neither economy experiences significant labour shortages.

In the short-run, the outcome for the national economy is quite different, highlighting the importance of period-by-period analysis in the policy evaluation process. In fact, the presence of bargained real wages at the regional level (as in the Bargaining and Flow Migration scenarios) brings about the highest GDP trajectories during the first six years of the policy shock. This is because national real and nominal wages fall by most relative to base in these scenarios: the short-run fall in Scottish employment following the labour efficiency shock is sufficient to contribute to an overall relative reduction in national employment, which itself is associated with a reduction in national real wages. With falling prices over this period, nominal wages also fall by most; providing a competitive national export market in these scenarios. The Flow Migration case provides a slightly higher GDP profile than the Bargaining set-up (GDP increases by £1,467.31m (0.23%) and £1,427.73m (0.22%) in each case, respectively), since the movement of labour supply to regions of higher demand relaxes labour market pressures and further reduces real wages relative to base. The two Wage Spillover cases provide the lowest short-run GDP outcome. In contrast to the long-run results, the presence of migration does affect overall GDP performance in the years immediately following the policy change in these cases. Although the relative increase in Scottish GDP is approximately the same for both of these scenarios, RUK GDP is higher in the short-run when interregional migration is possible (Figure E.13), and the effect is sufficient enough to result in a relatively larger increase in national GDP compared to base.

Regardless of the type of national economic constraint imposed via the labour market, the results suggest that a significant policy dilemma exists for policy evaluations in the short-run. GDP increases relative to base across all the labour market configurations and for the duration of the simulation period, but employment does not. The ordering of the magnitude of the employment effects are in line with that of GDP, but the direction of change of GDP and employment differs in the short-run: national employment falls relative to base in the immediate post-shock years. This occurs across all scenarios, as a result of the increase in the effectiveness of the labour supply, but nevertheless precedes a long-run relative increase in national employment for each configuration (Figure E.16).

Whilst the expansionary output effect of the policy shock is in line with regional and national government objectives, the reduction in employment is not. For some scenarios, employment is below base for a few years – employment returns to base by period 4 in the Flow Migration case – for other scenarios the policy problem is even more pronounced: the level of employment does not return to base until period 13 in the Wage Spillover (1) case.

3. Policy discussion and conclusions

Despite the shift in the policy stance to acknowledge the potential for national effects of regional policies, research into the effects of regional policy remains rather limited in scope, with the national and non-target region impacts being largely ignored (Taylor, 2002).

During its time in office, the UK Labour government has endorsed regional policy as a means of expanding national output and reducing spatial economic disparities (Department of Trade and Industry, 1998), and the most recent Treasury ‘Green

Book' (HM Treasury, 2003) suggests that policy-makers no longer assume that regional policies are subject to complete crowding out. Theoretically, national economic gains are now explicitly acknowledged, at least with reference to supply-side regional policies (HM Treasury, 2003). The results reported in this chapter are in line with the recent change in the Treasury's position, and they also identify a need for the consequences of this change to be systematically recognised in practice. I find that regional policy spillovers may be significant at the national level: an increase in labour efficiency in the Scottish traded sector – which is an expected outcome of certain elements of current Scottish government policy – does have both regional and national output and employment effects. Even for the case where the target economy is small relative to the non-target economy, and where there are fewest distortions in the operation of the regional and national labour markets (i.e. fully flexible real wages and interregional migration), there are aggregate changes in national economic activity in response to a region-specific productivity stimulus.

For each of the model configurations, the long-run outcome of the policy shock is an increase in national GDP and employment, with the specific characteristics of the regional labour markets being an important determinant of the extent of the stimulus, and the adjustment path of the economy. In the target economy, the direct efficiency stimulus leads to a long-run increase in economic output, as expected, and spillover effects do arise for the RUK. The configuration of the regional labour markets prove to be particularly important in establishing the direction of change in the non-target region: I find that the presence of interregional migration flows motivated by wage and unemployment differentials makes for a long-run relative fall in output and employment in the RUK, following a positive supply shock in Scotland. In fact, I find that quite different GDP and employment changes in the non-target region can be associated with labour market configurations that have quite similar overall long-run impacts on the target region. This suggests that simply studying policy impacts on the target region is likely to provide little indication of the impact on non-target regions. While the target-region results are sensitive to alternative versions of how regional labour markets function, other-region effects prove to be even more so.

Incorporating a time element into the study, alongside consideration of the regional and national effects of a shock, highlights a number of policy-related issues that have not been revealed by earlier studies that focus only on long-run equilibrium results or target economy effects. Firstly, the results illustrate that the adjustment path to long-run equilibrium is slow, as is the case for the results of the demand-side analysis in Chapter 3. National GDP is not close to its long-run values across each of the model scenarios until at least period 20, and longer for the target economy. From a policy perspective, this could be problematic, given the Treasury's ten-year time horizon for the evaluation of local development policy (HM Treasury, 1995). Not only do significant adjustments occur beyond period 10 in the regional and national economies, but the ordering of the size of the effects under different labour market scenarios changes outwith this time period also. On the basis of the Treasury's ten-year period of consideration, the 'best' outcome for the target region occurs in the Bargaining scenario, whereas this set-up provides the third-best outcome for Scotland in the long-run.

Secondly, the results reveal a significant policy dilemma during the recommended ten-year evaluation period. In the Scottish economy, in the periods immediately following the supply shock, regional employment falls as a result of the increase in labour productivity. The fall in employment is sufficient in magnitude to contribute to a fall in employment at the national level also. Simultaneously, regional and national output increase relative to base, caused by an improvement in export competitiveness. Since policy makers are concerned with both output and employment effects, this presents a predicament for evaluation: despite these short-run effects, in the long-run the shock results in a significant increase in employment and GDP for Scotland and the UK as a whole. Furthermore, whilst the target region experiences a short-run fall in employment, the non-target region enjoys an increase in employment for the duration of the evaluation period, and beyond, as a result of the policy shock in Scotland. Therefore, should the effects of the policy be considered in accordance with current Treasury evaluation criteria - i.e. acknowledging only target-region effects for a ten-year post-shock time horizon - the resulting policy conclusions could differ significantly from those derived from a more comprehensive approach such as that adopted here. Whilst under the Treasury's evaluation principles none of the outcomes are particularly satisfactory – the positive supply stimulus in the target region leads to the level of Scottish employment being relatively lower than base across all the model scenarios until at least period 7 – the approach adopted here identifies that the results are more favourable in the longer run for the target and national economies, and for the non-target region throughout the simulation period.

Thirdly, the interregional, multi-period, modelling framework helps to illustrate that the relative effects of the supply shock differ for the two regional economies not only in terms of the size and direction of the impact, but also with regards to the timing of the effects. The source of the shock differs for each region and this, combined with the effects of active capacity constraints in the target region, means that the RUK economy is slower to adjust. Furthermore, the relative impact of more flexible real wages and interregional migration differ in magnitude across the two regions.

Together, the results strengthen the case for more thorough research and advice on the consequences of regional policy. Without a detailed interregional framework of the type employed here, important impacts would remain undetected, and the policy evaluation process could result in misleading policy conclusions. This has important and wide-ranging consequences for policy design and evaluation. The differing regional impacts in terms of the size, timing and direction of change mean that official guidance on appropriate measurement techniques and frameworks for analysis are required. Although the Treasury has recently acknowledged the presence of spillover effects associated with supply-side policies in principle, this has not yet been properly reflected in Green-Book-based evaluations of policy in practice. An appropriate interregional framework ought to be developed, and ultimately embedded, in Treasury doctrine.

A useful extension of the analysis would be to incorporate more highly disaggregated data on the skills level of the labour market, since one of the Scottish government's policy priorities is to increase regional productivity via a more highly skilled and knowledgeable work force. An additional future research opportunity would be to examine the impact of an improvement in regional productivity that is paid for either by the regional government, the national government, or shared in cost by both institutions. In practice, the ‘costless’ policy counterfactual that I assume in this chapter may be unrealistic, since measures to increase productivity are likely to be costly, and may be funded through taxes to fund human capital augmentation or infrastructure investment, for example.

Chapter 5[1]

Analysing Changes in the UK Interregional CO_2 'Trade Balance': the Added Information Content of a Computable General Equilibrium Versus an Input-Ouput Methodology

1. Introduction

One overall objective of this thesis is to provide a more comprehensive analysis of regional policy impacts than that currently available in the literature or reflected in official appraisal methods. In Chapters 3 and 4, I consider the existence and nature of economic spillovers between the regions in response to an exogenous change in regional policy. I find that the AMOSRUK interregional CGE model of the UK provides a useful framework for exploring such issues. In this chapter, I provide a methodological contribution to the research, by demonstrating the potential usefulness of CGE relative to I-O modelling for regional policy. I address an additional current policy concern of the regional UK governments, this time related to measuring the extent of environmental spillovers between the regions. I consider the pollution content embedded in interregional trade flows, and the effects of changes in demand on the CO_2 'trade balance' between Scotland and the RUK. In doing so, I identify the additional information content of simulation results from a CGE framework, relative to that of an I-O model.

Recently, policy makers worldwide have emphasised the need to measure and account for pollution emissions that emanate from economic activity in individual countries. This is reflected in binding country-level and international agreements, such as the UK's Climate Change Act (2008)[2], which commits the government to

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[1] The research of this chapter has been published in part as an International Input-Output Association Working Paper (number WPIOX08-006), and has also been submitted in part for publication in the International Regional Science Review journal.

[2] The text of the Climate Change Act is available at http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080027_en.pdf

reducing greenhouse gas emissions by 34% by 2020 and 80% by 2050[3], and international obligations such as the Kyoto Protocol[4]. Under these arrangements, emissions are assigned to the country where they are produced, and no account is taken of the pollution embedded in the economy's imported goods[5]. Increasingly, however, attention has focused on acknowledging a broader responsibility for emissions generation, with consumption-based measures, such as carbon footprinting, gaining popularity. The choice of global accounting system has significant implications for assessing countries' emissions performance. In the UK, according to the producer-responsibility-principle of the Kyoto Protocol, emissions have fallen by around 15% over the period 1990 to 2005. However, when a wider, consumption-based measure of emissions is adopted, incorporating emissions related to international trade, UK emissions have increased over the same period by around 19% (Helm et al., 2007).

Such concerns have given rise to the concept of an emissions 'trade balance' between two countries: the measurement of pollution spillovers that result from inter-country trade flows. I-O analysis has proved to be a useful tool for examining issues such as the pollution embodied in production, consumption and trade flows under different accounting systems (Munksgaard and Pedersen, 2001). In particular, I-O analysis is now a commonly-used technique in the carbon footprint literature, where the emphasis is on attributing emissions according to the consumption accounting principle[6]. There have been various attempts to measure the extent of an emissions 'trade balance' associated with international trade for a number of countries, including contributions based on I-O accounting and modelling methods[7]. The issue is also an important one for regional economies, particularly given the close

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[3] Committee on Climate Change (2008) and the Chancellor of the Exchequer's Budget Statement (2009), which is available from http://www.hm-treasury.gov.uk/bud_bud09_speech.htm. The emissions targets are relative to a 1990 baseline (Department for Energy and Climate Change, 2009a).

[4] The text of the Kyoto Protocol, which sets out the binding targets for thirty-seven industrialised countries and the European Community for reducing greenhouse gas emissions, is available at http://unfccc.int/resource/docs/convkp/kpeng.pdf

[5] The Kyoto Protocol is based on the 'production accounting principle' (see Munksgaard and Pedersen, 2001).

[6] Wiedmann et al., 2007, provides a review.

[7] See, for example: Kondo et al. (1998); Munksgaard and Pedersen (2001); Sánchez-Chóliz and Duarte (2004); and Wyckoff and Roop (1994).

interregional trade linkages across regions within national boundaries, such as in the UK. In the context of a devolved UK economy, there is a growing awareness of the regions' role in helping to meet the environmental obligations embodied in the UK Climate Change Act and the Kyoto Protocol, and therefore in measuring the extent of emissions spillovers between the regional economies. In Turner et al. (2007), the authors derive an interregional I-O method that is suitable for accounting for emissions under the production and consumption accounting principles and determining interregional environmental ‘trade balances’, and in McGregor et al. (2008) the authors enumerate the CO_2 pollution content of UK interregional trade flows using an I-O framework.

Measuring the emissions production associated with final consumption in the economy is a crucial aspect of any quantification of an interregional environmental 'trade balance'. In this sense, an I-O methodology is appropriate for examining such issues. At the core of I-O analysis is a set of sectorally and (data permitting) regionally disaggregated economic accounts, which identify sectoral production inputs, and the subsequent uses of the output of these sectors. The interdependencies of different activities across the regions can be quantified, as can all direct, indirect and induced resource use associated with that consumption (Leontief, 1970, Miller and Blair, 1985). Thus the pollution flows embedded in that consumption can also be measured in each region (Wiedmann et al., 2007).

However, the usefulness of I-O modelling is reduced when interest shifts to measuring the impact of *changes* in policy or economic activity on the environmental ‘trade balance’. As I have noted previously in this thesis, a conventional demand-driven I-O model assumes an infinitely elastic supply-side in the economy and is also restricted by the assumption of universal Leontief (fixed proportions) technology[8]. In so far as these assumptions are believed to be unrealistic in practice, a more flexible framework is required for analysing marginal changes in activity or policy, when supply-side or technological characteristics will likely play a crucial role in determining the adjustment path of the economy. In Chapters 3 and 4, for example, I

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[8] See Chapter 2, Section 7.3 for further discussion.

demonstrate that different model assumptions regarding the existence and nature of supply side constraints can significantly affect the economy's response following an exogenous change in demand- or supply-side policy.

Such marginal impact analysis of interregional emissions spillovers is likely to be an important concern for UK regional policy makers. The UK's commitment to the Kyoto Protocol is a national obligation, and interregional CO_2 'trade balance' analysis facilitates the discussion about the degree to which devolved authorities should play a part in meeting such national targets. However, devolved authorities such as the Scottish Parliament have limited policy instruments at hand to control the extent of emissions within the region. This is particularly true with respect to emissions that result from changes in activity in other regions, which could therefore give rise to issues of policy co-ordination amongst the regional authorities. The research in this chapter therefore helps to illustrate some important issues regarding the regional environmental gains and losses that emanate from changes in other-region demand, and the potential difficulties associated with attributing responsibility for pollution across the regions when interregional trade-related emissions are accounted for.

In this chapter I argue that a CGE approach, which models behavioural relationships in a more realistic and theory-consistent manner, potentially has a higher information content than I-O analysis for the purposes of conducting this type of regional environmental policy evaluation. CGE modelling is established as a prevalent approach in the literature for analysing a wide range of environmental issues at a regional, national and global level[9]. Environmental extensions of the AMOS framework (Harrigan et al., 1991) have been developed for Scotland (Hanley et al., 2006) and the UK (Allan et al., 2007b), which thus far have primarily been used to consider the economy-wide impacts of improvements in energy efficiency. To date, CGE models have not been used to consider the impact of policy changes or marginal economic impact analysis on the pollution content of international or

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[9] See Bergman (2005) for a review.

interregional trade. The research in this chapter therefore provides a novel extension to the existing I-O based environmental 'trade balance' literature.

I use the AMOSRUK interregional CGE model to demonstrate the potential contribution of CGE modelling techniques to regional environmental 'trade balance' analysis. To do so, I simulate the effects of a positive regional demand shock to the RUK economy within the interregional CGE framework, and the consequent impact on the CO_2 'trade balance' between Scotland and the RUK is measured. The results are compared to equivalent interregional I-O simulation results[10]. The CGE and I-O models share the same I-O database, but I argue that the active supply-side and more theory consistent specification of production and consumption behaviour of the CGE model make it a more appropriate methodology for this type of spatially disaggregated energy policy evaluation. For the CGE simulations, I also consider how alternative configurations of the regional and national labour markets affect model results, including the impact on the interregional CO_2 'trade balance', to further demonstrate the potential added value of the technique.

There are a number of data limitations associated with the construction of the interregional I-O and SAM data used in this paper. These are explained in detail in McGregor et al. (2008), and relate primarily to: the lack of timely analytical I-O tables and interregional trade data for the UK; and issues regarding consistency across the economic and environmental, and regional and national data. Consequently, the quantitative results of this analysis are provisional. Nonetheless, the framework is useful for an illustrative analysis in order to examine the nature and extent of regional interdependence in the UK, specifically relating to the existence of regional environmental CO_2 spillovers, and the impact on these variables when a

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[10] The I-O simulations and pollution attribution calculations are drawn directly from a separate study, of which I am a co-author (Turner et al., 2009). The I-O framework and pollution attribution methodology are also taken from other studies (McGregor et al., 2008; Turner et al., 2007). These parts of the research are not intended to be an examinable component of this thesis. The I-O results are included here for the purposes of comparison only. The contribution of this chapter to the PhD research is the CGE simulations and analysis, which is carried out with the objective of demonstrating the added information content of the CGE results relative to that of the I-O methodology.

demand shock is applied to the system. The main focus of the paper is not its quantitative aspect, but rather to demonstrate the potential added value of CGE relative to I-O analysis for this particular type of regional concern.

The remainder of the chapter is organised as follows. In Section 2 I present the I-O methodology. I describe the interregional I-O methodology of Turner et al. (2007) and McGregor et al. (2008) for enumerating the pollution content of interregional trade flows, and for calculating the base year (1999) CO_2 'trade balance' between Scotland and the RUK. I also describe the I-O results (from Turner et al., 2009) associated with a positive export demand stimulus to the RUK regional economy on key economic variables for each region and the interregional CO_2 'trade balance'. In Section 3, I present the CGE methodology. I use the AMOSRUK interregional CGE model, which is identical to the model used in Chapters 3 and 4 of this thesis, but with a different sectoral aggregation, for a comparable CGE analysis. The AMOSRUK model shares the I-O database of the interregional I-O model of Section 2, but introduces an active supply-side and more theory-consistent specification of production and consumption behaviour (in particular, relaxing the assumption of universal Leontief technology). I simulate an equivalent positive export demand stimulus to the RUK region within the AMOSRUK model, incorporating alternative specifications of the labour market. I consider the effects of the stimulus on key variables, and describe the consequential impact on UK interregional CO_2 spillovers. These results are compared to that of the I-O approach of Section 2. In Section 4 I discuss some policy implications of the analysis and provide concluding comments. Appendices F and G contain all tables and figures, respectively, relating to this chapter.

2. The I-O methodology

In this section, I draw on the results of Turner et al. (2009), in which the authors use an interregional I-O framework (from Turner et al., 2007 and McGregor el al., 2008) to calculate the UK economy-wide effects of a regional demand stimulus, and the impact on the interregional CO_2 'trade balance'.

2.1 The interregional I-O framework

In Turner et al. (2007), the authors demonstrate an analytical I-O method for enumerating the pollution content of interregional trade flows. The authors begin with a central, single region, I-O equation (Leontief, 1970; Miller and Blair, 1985):

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{5.1}$$

where $\mathbf{x}$ is a $N \times 1$ vector of gross outputs with elements x_i , where $i = 1, \dots, N$ for each economic sector, i, and $\mathbf{y}$ is an $N \times 1$ vector of final demands with elements y_i. $\mathbf{A}$ is the technical coefficients matrix with elements a_{ij}, where $j = 1, \dots, M$ and $M = N$. The $\mathbf{A}$ matrix describes the intermediate demand for the output of domestic sector i required by domestic sector j for each unit of output x_j from sector j. $\mathbf{I}$ is the identity matrix. The $N \times N$ Leontief inverse is defined as $(\mathbf{I} - \mathbf{A})^{-1}$ with elements b_{ij}, describing the amount of output generated in each sector i for each unit of final demand for the output of sector j.

This standard I-O framework is augmented with a vector of output-pollution coefficients where there are K pollutants. Total pollution generation in production is defined as:

$$\mathbf{f}^{\mathbf{x}} = \mathbf{\Phi}\mathbf{x} \tag{5.2}$$

where $\mathbf{f}^{\mathbf{x}}$ is a $K \times 1$ vector, with element f_k^x, where $k = 1, \dots, K$, representing the physical amount of pollutant k generated within the economy through the production of the vector of gross outputs, $\mathbf{x}$. $\mathbf{\Phi}$ is a $K \times N$ matrix where element $\Phi_{\mathrm{k,i}}$ is the amount of pollutant k per unit of gross output in sector i. In this case, $K = 1$, and k is a single pollutant, CO_2.

Augmenting Equation (5.1) and Equation (5.2):

$$\mathbf{f}^{\mathbf{y}} = \mathbf{\Phi}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y} \tag{5.3}$$

which relates the $K \times 1$ vector of total pollutants generated in production to the $N \times 1$ vector of final demand.

Turner et al. (2007) extend this single region framework to a two region case[11]. From Equation (5.1), the final demand $\mathbf{y}$ is separated into: local final demand in region 1 for commodities produced in region 1 $(\mathbf{y}_{11})$; local final demand in region 2 for commodities produced in region 2 $(\mathbf{y}_{22})$; export demand in region 2 for commodities produced in region 1 $(\mathbf{y}_{12})$; and export demand in region 1 for commodities produced in region 2 $(\mathbf{y}_{21})$:

$$\begin{pmatrix} \mathbf{x}_{11} & \mathbf{x}_{12} \\ \mathbf{x}_{21} & \mathbf{x}_{22} \end{pmatrix} = \begin{pmatrix} \mathbf{I}-\mathbf{A}_{11} & -\mathbf{A}_{12} \\ -\mathbf{A}_{21} & \mathbf{I}-\mathbf{A}_{22} \end{pmatrix}^{-1} \begin{pmatrix} \mathbf{y}_{11} & \mathbf{y}_{12} \\ \mathbf{y}_{21} & \mathbf{y}_{22} \end{pmatrix} \tag{5.4}$$

Here, $\mathbf{x}_{\mathbf{ij}}$ is an $\mathrm{N} \times 1$ vector giving output of sectors in region i generated by the consumption demands (domestic and imports) of region j. Scotland is assumed to be region 1 and the rest of the UK is assumed to be region 2. The framework is aggregated to 3 sectors to allow for compatibility with the 3 sector interregional CGE model, AMOSRUK. Each region therefore has $i = 1, \dots, N = 3$ production sectors producing $j = 1, \dots, N = 3$ commodities. Submatrices $\mathbf{A}_{\mathbf{rs}}$ contain elements a_{ij}^{rs}, describing the transactions between production sector i in producing region r and consuming sector j in consuming region s, for each unit output of sector j in region s. $[\mathbf{I}-\mathbf{A}]^{-1}$ is the partitioned interregional Leontief inverse, which separates out the gross output multiplier for each sector in each region into gross outputs that are induced by domestic and by traded final demand. Thus by partitioning the $\mathbf{A}$-matrix into local and imported intermediate consumption for both regions, and by separating the $\mathbf{y}$ vector into local and traded final demand for both regions, it is therefore possible to identify how activity in one region affects activity in the other region.

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[11] See Allan et al. (2004) for an extension to a multi-region framework.

As for the single region case, this framework can be extended to consider the issue of pollution spillovers between two regions. Equation (5.4) is augmented with a $(1 \times N)$ vector of output-pollution coefficients for a single pollutant (CO_2), $\boldsymbol{\Phi}^{\mathbf{x}}$, which shows the direct CO_2 intensity of output in each production sector i for each region:

$$\begin{pmatrix} \mathbf{f}_{11}^{\mathbf{y}} & \mathbf{f}_{12}^{\mathbf{y}} \\ \mathbf{f}_{21}^{\mathbf{y}} & \mathbf{f}_{22}^{\mathbf{y}} \end{pmatrix} = \begin{pmatrix} \boldsymbol{\Phi}_1^{\mathrm{x}} & 0 \\ 0 & \boldsymbol{\Phi}_2^{\mathrm{x}} \end{pmatrix} \begin{pmatrix} \mathbf{I} - \mathbf{A}_{11} & -\mathbf{A}_{12} \\ -\mathbf{A}_{21} & \mathbf{I} - \mathbf{A}_{22} \end{pmatrix}^{-1} \begin{pmatrix} \mathbf{y}_{11} & \mathbf{y}_{12} \\ \mathbf{y}_{21} & \mathbf{y}_{22} \end{pmatrix} \tag{5.5}$$

$$= \begin{pmatrix} \boldsymbol{\Phi}_1^{\mathrm{x}}\mathbf{L}_{11}\mathbf{y}_{11} + \boldsymbol{\Phi}_1^{\mathrm{x}}\mathbf{L}_{12}\mathbf{y}_{21} & \boldsymbol{\Phi}_1^{\mathrm{x}}\mathbf{L}_{11}\mathbf{y}_{12} + \boldsymbol{\Phi}_1^{\mathrm{x}}\mathbf{L}_{12}\mathbf{y}_{22} \\ \boldsymbol{\Phi}_2^{\mathrm{x}}\mathbf{L}_{21}\mathbf{y}_{11} + \boldsymbol{\Phi}_2^{\mathrm{x}}\mathbf{L}_{22}\mathbf{y}_{21} & \boldsymbol{\Phi}_2^{\mathrm{x}}\mathbf{L}_{21}\mathbf{y}_{12} + \boldsymbol{\Phi}_2^{\mathrm{x}}\mathbf{L}_{22}\mathbf{y}_{22} \end{pmatrix}$$

The first subscript on each element of Equation (5.5) identifies the producing region, r, and the second the consuming region, s. f_{rs}^{y} is a scalar representing the amount of CO_2 generated in production activities in region r to support region s final demand, for output produced in region r, $\mathbf{y}_{\mathrm{rs}}$ (which is a $N \times 1 = 3 \times 1$ vector). $[\mathbf{I} - \mathbf{A}]^{-1}$ is the symmetric $2N \times 2N$ (6×6) partitioned interregional Leontief inverse (multiplier) matrix, with elements b_{ij}^{rs} describing the amount of output of each producing sector i in region r required per unit of final demand for the output of consuming sector j in region s. Thus $\mathbf{f}_{11}^{\mathbf{y}}$ tells us the amount of CO_2 that is used in production activities in region 1 to support final demand in region 1. $\mathbf{f}_{21}^{\mathbf{y}}$ is the amount of CO_2 that is used in production activities in region 2 to support final demand in region 1, and so on.

The above description of the interregional Leontief inverse is consistent with the conventional Type I case where the **A**-matrix has elements a_{ij}^{rs} representing the amount of output produced by each sector i in region r, x_{ij}^{rs}, required as input to production per unit of total input/output in consuming sector j in region s, X_j^s. Thus, each element of the **A**-matrix is formally defined as follows:

$$a_{ij}^{rs} = x_{ij}^{rs}/X_j^s \tag{5.6}$$

For standard Type I I-O analysis, the production sectors are those which are identified in the country's I-O tables. In this research, a Type II I-O analysis, whereby household consumption is endogenised in the system, is more appropriate. This makes the I-O results more comparable with that of the CGE model, where household income and expenditure is determined endogenously within the framework[12].

McGregor et al. (2008) redefine the **A** and **Y** matrices of the above system so as to endogenise activities recorded as final consumption sectors in the I-O accounts - i.e. which are therefore initially included in the partitioned **Y** matrix in the Type I case. The approach of McGregor et al. (2008) is followed here. The authors endogenise household consumption by subtracting household final consumption expenditure from each vector $\mathbf{y}_{\mathrm{rs}}$, and adding an extra column and row of I-O coefficients to the **A**-matrix. Thus households move into the production block as a fourth sector in each region. In the additional row, x_{ij}^{rs} records the use of region r household production (the additional production sector, i) as inputs to production in sector j in region s and X_j^s will be the total input/output of sector j in region s. Since in an I-O table household production is comprised of the provision of labour services only, the additional row entries will be payments to labour services or income from employment, divided by total sectoral input/output. In the additional column, x_{ij}^{rs} will record use of local inputs from each production sector, i, by the household sector, j (formerly recorded as final consumption) and X_j^s as the total input/output of households in region s, which is given by total payments to labour/income from employment.

Assuming that final consumers also directly generate CO_2 emissions, these are incorporated with a $1 \times Z$ vector, $\mathbf{\Phi}_r^y$, of coefficients for each final consumption group z in region r. Each element Φ_z^r describes the physical amount of CO_2 that is

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[12] There will not be an exact correspondence between the I-O and CGE analyses, since the CGE framework includes non-wage household income. Also, since household expenditure does not tend to balance with household income in an I-O framework (since not all elements of income and expenditure are included), strictly speaking a portion of household expenditure should be retained as being exogenously determined, or alternatively a SAM should be used in place of the I-O accounts.

directly generated per unit of final expenditure. Here, only one final consumption group, households (hh), generate direct emissions, so $z = hh = 1$, and this emissions generation only takes place in the home region. So:

$$\begin{pmatrix} f_1^{hh} & 0 \\ 0 & f_2^{hh} \end{pmatrix} = \begin{pmatrix} \Phi_1^{hh} & 0 \\ 0 & \Phi_2^{hh} \end{pmatrix} \begin{pmatrix} y_1^{hh} & 0 \\ 0 & y_2^{hh} \end{pmatrix} \tag{5.7}$$

By summing the partitioned matrices in Equations (5.5) and (5.7), McGregor et al. (2008) are able to measure all emissions in regions 1 and 2 that are attributable to final consumption demand in each region for the outputs of both regions. Total emissions generated in Scotland (region 1) are found by summing along the first row of each **f** matrix so that:

$$f_1^y = f_{11}^y + f_{12}^y + f_1^{hh} \tag{5.8}$$

And total emissions in both regions of the UK that are attributable to Scottish (region 1) final consumption demand are found by summing down the first column of each **f** matrix so that:

$$f_1^y = f_{11}^y + f_{21}^y + f_1^{hh} \tag{5.9}$$

In accordance with the Munksgaard and Pedersen's (2001) consumption accounting principle, Scotland's CO_2 'trade balance' with the RUK is calculated as the difference between Equations (5.8) and (5.9)[13], which equals $f_{12}^y - f_{21}^y$.

In the framework outlined above, the treatment of interregional trade between Scotland and the RUK is in accordance with the consumption accounting principle, such that CO_2 generation within the UK regions is attributed to consumption demand in the UK. However, since the UK is an open economy, the I-O system of Equation

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[13] The corresponding calculations for RUK are carried out using the second row and column of the **f** matrix.

(5.5) would need to be extended to incorporate foreign trade in order for the calculation to adhere to Munksgaard and Pedersen's (2001) consumption accounting principle. In this analysis, for the sake of simplicity (and in the absence of an appropriate data set to adopt the consumption accounting principle for ROW trade), the system is closed by applying the production accounting principle to trade with the ROW[14]. This means that emissions generated in Scotland that are attributable to ROW exports are assigned to Scotland's pollution account, and similarly emissions generated in the RUK that are attributable to ROW exports are assigned to the RUK's pollution account. Thus Equation (5.5) does not fully represent Scottish emissions according to the consumption accounting principle.

2.2 Calculating the base case Scotland-RUK CO_2 'trade balance'

The above framework is used to consider the nature and extent of UK interregional interdependence with regards to environmental spillovers. In this section, Scotland's CO_2 'trade balance' with the RUK is enumerated, in order to consider whether Scotland directly or indirectly imports more or less emissions than it exports to the RUK.

Table F.1 shows the results of estimating Equation (5.5) with household expenditure endogenised within the interregional **A**-matrix (i.e. for the Type II case). All CO_2 emissions generated across the UK regions are allocated to the remaining final demand categories in each region. The results show the extent of CO_2 spillovers that occur between Scotland and the RUK. Of the total CO_2 generated in the UK directly or indirectly as a result of conventional Scottish final demand expenditures, just over 45% is generated in RUK (i.e. not in Scotland). A smaller, but still significant, proportion (just over 38%) of CO_2 generated in Scotland is to support, directly or indirectly, RUK final demand. Also note that Scottish exports to the ROW, which produce no direct CO_2 outwith Scotland, still generate sizeable amounts of CO_2 in the RUK as a result of the indirect impacts of the production of intermediate inputs.

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[14] Other authors attempt a pollution attribution analysis according to the consumption accounting principle, including for foreign trade (e.g. Druckman et al., 2008).

The same is true for the impact of RUK exports to the ROW in terms of CO_2 emissions in Scotland.

There is a negative CO_2 'trade balance' for Scotland, implying that the pollution generated in Scotland by production that is attributable to RUK final demands is less than the pollution generated in the RUK by production that is attributable to Scottish final demands. This Type II Scottish CO_2 trade deficit equates to around 13% of total CO_2 generated in Scotland. Note, however, that the precise levels and proportions of emissions attributable to different activities, and the size of the CO_2 'trade balance' in Table F.1 are dependent on the Type II assumption that is used here. McGregor et al. (2008) analyse the impact of adopting different assumptions (Type I and TELAS[15]) in the same framework. The authors show, for example, that when trade is endogenised, under the TELAS assumption, Scotland's CO_2 trade deficit becomes a surplus, due to Scotland being a net exporter to the ROW, while the RUK region is a net importer.

2.3 I-O results: the impact of a change in regional demand on the Scotland-RUK CO_2 'trade balance'

The analysis above is an accounting exercise, whereby CO_2 emissions generated in the UK in the year to which the accounts relate (1999) are attributed to different elements of final demand for UK production. The elements of the A-matrix are taken to indicate average input requirements in 1999, and the multipliers given by the Leontief inverse matrix signify, on average, what levels of activity, including pollution generation, are supported by different types of final demand during this time period. However, multipliers can also be interpreted as representing how activity would change if final demands increase or decrease. This transforms the I-O accounting framework into a model and, as with all models, requires that a number of assumptions are adopted.

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[15] Trade Endogenised Linear Attribution System.

In this analysis, a 10% increase in export demand from the ROW to the RUK 'primary, manufacturing and construction' sector is applied to the system, and the consequential impact on the Scotland-RUK CO_2 ‘trade balance’ is measured. Table F.2 defines the sectors within the Scottish-RUK interregional I-O framework. This is not intended to represent a realistic or expected demand shock, and the source of the stimulus is not considered here. Rather, the intention is to illustrate the importance of interregional trade linkages in modelling the impacts of a marginal change in economic activity in the context of the regional issue discussed above.

The shock is introduced to the model by changing the value of the y_2^{ROW} vector in the matrix of final demand in Equation (5.5) to represent a 10% increase in ROW export demand to sector 1 in region 2, the RUK. Table F.3 shows the impacts of the disturbance (in terms of percentage changes, given by the base of the 1999 I-O tables) on: sectoral output (income from employment in the case of households); value-added (equating to GDP at basic/producer prices); employment; and direct CO_2 emissions. This simple numerical example is intended to draw attention to qualitative issues in terms of the type of results that can be obtained from I-O and CGE models.

There are two key points to note in examining the I-O results in Table F.3. Firstly, at the sectoral level the percentage change in each variable is the same. This is due to the assumption of Leontief technology (i.e. that if output changes by X%, the use of all inputs changes by X%). Secondly, there is no indication as to the time taken to reach the new post-shock equilibrium. These issues are discussed in more detail below.

The post-shock CO_2 attribution and ‘trade balance’ analysis is shown in Table F.4. This is comparable with Table F.1 above, and the difference between the two tables is shown in percentage terms in Table F.5. In terms of the impact of the shock, the key result to note is that Scotland’s CO_2 ‘trade balance’ improves in response to this shock. The deficit in Table F.4 is reduced relative to the base case shown in Table F.1. Table F.5 shows that the driver of this result is the fact that the amount of pollution generated in Scotland to support RUK final demand has risen by 6.72%. This leads to an 8.41% reduction in the size of Scotland's CO_2 trade deficit with the RUK. Almost half (46%) of this change in the CO_2 'trade balance' is due to the increase in emissions from the Scottish Electricity, Gas and Water Supply sector. This sector in Scotland is heavily trade-reliant, exporting almost 26% of its output to RUK in the base year of 1999 (in contrast to the RUK Electricity, Gas and Water Supply sector, which exported less than 1% of its output to Scotland in 1999).

However, the key point in terms of the methodological issues being discussed here is that the increase in Scottish and RUK emissions to support RUK final demand is the only change in Tables F.4 and F.5. This reflects the fact that there is no response in any other type of final demand, and this would not be expected given that (a) all other final demands are determined exogenously; (b) even if other final demands were determined endogenously, there is no change in prices to stimulate further changes. In the CGE analysis, none of these assumptions is maintained.

3. The CGE methodology

The objective of this paper is to investigate the potential added value of using a CGE methodology to analyse the impact of marginal policy changes on the UK interregional CO2 'trade balance' relative to the I-O accounting analysis above. I argue that the usefulness of the interregional I-O framework discussed above is limited for impact analysis in the current context. First, the system in Equation (5.5) is a conventional demand-driven I-O model in which price effects are absent since it assumes that all supply is infinitely elastic in response to changes in final demand, where all final demand is determined exogenously. Moreover, it is further restricted by the assumption of universal Leontief (fixed proportions) technology implied by the use of the **A** and Leontief multiplier matrices in production. The implication of this assumption is that if relative prices change, there is no input substitution as all goods and services are complements in production in consumption, as demonstrated in the I-O modelling analysis of Section 2.3.

It is possible to construct a supply-driven I-O model (Oosterhaven, 1988, 1989) or a price dual to the demand model (Leontief, 1970, Allan et al., 2007a). However, in each case, the assumption of universal Leontief technology remains, and it is only possible to model supply *or* demand, or prices *or* quantities. That is, supply or demand must be passive (i.e. infinitely elastic) and only prices or quantities can be considered. I argue here that, where analysis of marginal changes in activity is required, a more flexible interregional CGE approach is more appropriate and informative, since the method allows for more realistic and theory-consistent behavioural relationships to be modelled.

As discussed in Chapter 2, CGE models provide a more flexible approach to modelling both supply and demand behaviour, and they allow the researcher to consider how both prices and quantities may change in response to a change in activity. For example, in the case of an increase in export demand, there will be crowding out in the domestic economy if there are short-run supply constraints on capital stocks or labour supply. This will lead to competition amongst production sectors for the use of limited factor inputs, thereby increasing the return on these factors. This will feed through to local price and competitiveness effects. In turn, this will affect existing levels of intermediate and final demands - i.e. both will respond endogenously, assuming that the assumption of universal Leontief technology is relaxed (in this case, by using CES functions). However, a change in factor returns will also induce a change in factor supplies, such that capacity constraints relax in the long-run. For example, if the return on capital increases, this will lead to an increase in capital stock by stimulating investment, or to an increase in the supply of labour if regional wages rise relative to other-region wages, thereby inducing in-migration. In this sense, McGregor et al. (1996b) argue that an I-O equilibrium (i.e. one where relative prices are unchanged relative to the initial equilibrium) may be replicated in the long-run in a CGE analysis of a pure demand disturbance. However, in the presence of constraints on the expansion of factor supplies, such as national or regional migration restrictions, a long-run I-O equilibrium will not be replicated. In contrast, such constraints can be modelled in a

CGE framework[16].

Importantly, in the AMOSRUK model, the adjustment process of the economy from one equilibrium to another can be traced over time, as the supply of different factors respond to changes in returns. Furthermore, it is possible to integrate a number of alternative theoretical perspectives, different market conditions and macroeconomic closures. In Chapters 3 and 4, I find that by considering a range of different supply-side specifications - relating to the configuration of the national and regional labour markets and the determination of wages - important policy insights are revealed. In this chapter, I also consider how different labour market assumptions affect the model results.

3.1 AMOSRUK: an interregional CGE framework

The structure of the CGE model used for the simulations is identical to that used in Chapters 3 and 4. As previously, the model database incorporates an interregional, multi-sectoral I-O framework, which is augmented to incorporate information on income transfers between economic agents in a SAM. However, in order to ensure comparability with the I-O results above, in this chapter the aggregation of the CGE model database differs from that of earlier chapters. Here, the model shares the database of the I-O framework of Section 2.1, and the model is aggregated to three sectors: the 'primary, manufacturing and construction' sector; the 'electricity, gas and water supply' sector; and the services sector. These differ from the sector aggregation of previous chapters: the 'manufacturing' sector; the 'non-manufacturing traded' sector; and the 'services' sector. McGregor et al. (2008) describes the construction of the interregional I-O and SAM databases.

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[16] Furthermore, when simulating a supply-side scenario such as the increase in labour efficiency considered in Chapter 4, there will be permanent changes in prices, such that an I-O equilibrium would not be reproduced, even in the long-run. Nonetheless, the introduction of supply-side disturbances poses some difficulties within an I-O framework, given that: supply *or* demand is assumed passive; only prices *or* quantities are modelled; and technology is of fixed Leontief form.

The full AMOSRUK model listing is provided in Appendix A. However, I outline here the main AMOSRUK features that allow a more detailed and appropriate analysis of the impact of a marginal change in regional demand on UK interregional emissions spillovers, relative to that of the I-O Equation (5.5). It is worth noting that I do not presume that a CGE approach is more suitable and informative than I-O methods in all circumstances; rather I suggest that in the context of analysing this particular policy issue - the impact of marginal changes on the CO_2 'trade balance' - the AMOSRUK simulations have additional informational content that is useful for policy analysis over and above that of the specific I-O Equation (5.5).

There are a number of key characteristics of the AMOSRUK framework via which the CGE simulations add value in this policy context. Firstly, this includes the ability to incorporate substitutability between factors of production (labour, capital, locally supplied intermediates, other-region imports, ROW imports) and final consumption expenditure on goods and services (as production, excluding capital and labour), in response to changes in relative prices. Secondly, the framework incorporates price sensitivity of interregional and international exports. All non-price determinants of ROW export demand are assumed to be exogenous, but interregional exports are fully endogenous and depend on relative prices and the structure of all elements of intermediate and final demand in the other region. Thirdly, labour and capital stocks are updated between periods. Capital stocks are determined endogenously: in each period, sectoral investment demand is equal to depreciation plus a proportion of the difference between actual and desired capital stocks. In response to a shock, investment optimally adjusts capital stocks, gradually relaxing any capacity constraints. The labour force can also be updated following a shock. In the current application I assume that there is no natural population increase and no international migration. In the Flow Migration labour market scenario detailed below, I assume that regional labour forces can be adjusted through interregional migration within the UK. Finally, the framework allows for the period-by-period adjustment process of the model results to be considered. Given the annual data in the base year SAM, each period can be interpreted as one year. As in Chapters 3 and 4, this allows me to consider the adjustment path of the economy over time with reference to the UK government's ten-year time limit for regional policy evaluation, and also the relative speed of adjustment of the regional economies.

3.2 The AMOSRUK simulation methodology

For the AMOSRUK CGE simulations, I replicate the demand disturbance introduced to the interregional I-O model in Section 2.3. I consider the system-wide effects on Scotland and the RUK of a 10% increase in ROW export demand for the outputs of the RUK 'primary, manufacturing and construction' sector. The objective is to provide an illustrative example of the added analytical content of a CGE analysis over and above the I-O analysis of Section 2 in the context of exploring the effects of a demand shock on the UK interregional CO_2 'trade balance'. It is intended to demonstrate the ability of the framework to capture, for example, crowding out effects due to supply constraints (on labour and capital) in the short to medium run, and the consequences for prices and competitiveness where all (intermediate and final) demands are determined endogenously and the assumption of Leontief technology is relaxed.

I simulate the regional demand stimulus under three different wage-setting and migration assumptions, each of which represents different theoretical perspectives about the supply-side specification of regional economies[17]. The labour market assumptions include three of those considered in earlier chapters (the Quasi I-O, Bargaining and Flow Migration cases), and a full description of each provided in Appendix B.

In each simulation, the export stimulus is introduced as a permanent step increase in demand in period 1 and the model is run forward for 75 periods (years). As in the I-

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[17] It would also be possible to model the impact of a marginal change in supply-side activity on the CO_2 'trade balance', though I focus on a demand-side change for the sake of comparison with the I-O results. However, the flexibility of the CGE model structure allows me to demonstrate how alternative specifications of supply-side behaviour at the regional and national levels affect model results.

O analysis in Section 2.3, the values of all other exogenous variables are held constant, and I report the changes from the initial base-period value for the key variables. Crucially, though, all export demands are determined endogenously and respond to the relative price changes that occur in response to the initial exogenous demand shock. In all cases, investment is endogenous and sectoral capital stocks are updated between periods.

The model calibration process takes the economy to be initially in long-run equilibrium, so that if the model is run forward with unchanged exogenous variables and parameters, the endogenous variables continuously take their initial values. Introducing a step change drives the economy towards a new long-run equilibrium, and it is the paths to the new, comparative static, equilibria that are reported here. The different model configurations generate both different long-run equilibria and different adjustment paths.

For each simulation, the model results are used to create a new interregional I-O table (incorporating the impacts of the demand shock) and this is used to estimate the environmental ‘trade balance’ between Scotland and the RUK using Equations (5.8) and (5.9) above. In all cases, there is a qualitative difference in the environmental ‘trade balance’ results compared with the I-O case presented in Section 2.3, in terms of (i) the different stages of the adjustment process with crowding out at the sectoral and regional level out due to the presence of supply constraints in early periods; (ii) the impact of endogenous prices and final demands.

3.3 CGE results: the economic impact of a regional demand stimulus

3.3.1 Quasi I-O: RUK economy results

Figure G.1 illustrates the simulated impact of the demand shock on RUK GDP under each of the labour market configurations, with the RUK being the region directly impacted by the demand shock. In all cases, the export stimulus leads to an increase in GDP relative to base towards a new, stable equilibrium. The relative increase is greatest for the Quasi I-O configuration, with RUK GDP 2.80% above its base value by period 75 (which is slightly greater than the increase in total RUK value-added (2.63%) in the I-O case). The economy is converging on a long-run equilibrium by period 75, though the size of the demand shock means that the economy has not yet fully adjusted by this period.

As in the I-O model, the demand shock leads to an increase in output in the RUK 'primary, manufacturing and construction' sector, and also in the wider economy, via an increase in the demand for intermediate inputs. However, in the early periods following the shock, supply constraints arise due to short-run capital fixity. As commodity outputs increase due to the demand stimulus, prices rise in the short-run. There is upward pressure on the price of commodity outputs, value added and capital rental rates in the 'primary, manufacturing and construction' sector, and also on the overall CPI (see Figure G.2). Prices rise in the other two RUK sectors, the electricity, gas and water supply sector and the services sector, due to the general increase in consumption demand, and also because intermediate inputs from these sectors are required in the 'primary, manufacturing and construction' sector production process. The effects are most significant in the electricity, gas and water supply sector, reflecting the importance of energy as an input to the manufacturing production process, though the effects are still less strong than in the 'primary, manufacturing and construction' sector itself. Prices in this sector are 1.50% higher than base values by period 3, compared with relative increases of 0.25% and 0.11% in the electricity, gas and water supply sector and the services sector respectively.

With fixed real wages in this scenario, as output expands, nominal wages rise (Figure G.3), but only in response to the increase in the CPI in the shorter-run (Figure G.2). This does result in a negative competitiveness effect in the short-run, though this is reversed over time, and there is no adverse competitiveness effects generated specifically through the labour market in this scenario as export demand expands. However, due to the increase in prices when supply is constrained, there is a loss in competitiveness, with the implication that the initial 10% increase in ROW export demand to the 'primary, manufacturing and construction' sector is not realised from the outset (indeed by period 75, only a 9.94% increase is achieved). However, as prices and nominal wages converge towards their long-run equilibrium values in the Quasi I-O scenario, this labour market configuration results in the highest increase in ROW exports over base (Figure G.7), and the external export boost contributes to the strongest RUK GDP trajectory for this configuration relative to the other scenarios (Figure G.1). In line with the increase in GDP, the export shock increases the derived demand for labour across all sectors. The long-run employment effects are strongest in this scenario out of all the labour market configurations (Figure G.4), with total employment 2.69% above base by the end of the simulation period.

3.3.2 Quasi I-O: Scottish economy results

In this scenario, the RUK export shock also leads to a rise in long-run GDP in Scotland. As in the RUK economy, the impact of the demand shock on Scottish GDP is significantly stronger under the Quasi I-O set-up than for the other labour market configurations (Figure G.8). The size of the impact as a percentage of GDP is, as expected, less significant for Scotland relative to the RUK, owing to the direct effect of the shock on the RUK economy.

In the Scottish economy, the stimulus results from an increase in the demand for Scottish intermediate goods by RUK producers, and also, in the longer-run as activity expands in the RUK, for final consumption and investment goods. As in the RUK economy, real wages remain fixed in Scotland. This means that as output expands, the Scottish economy does not experience negative competitiveness effects generated directly through the labour market. However, nominal wages increase in line with a rise in commodity outputs and the associated increase in CPI in the short-run. This brings about a significant negative external competitiveness effect. As such, Scottish exports to the ROW fall by 1.85% in period 3 (Figure G.14), and this contributes to the short-run fall in overall GDP relative to base (Figure G.8). Over time, as capacity constraints relax and prices move back towards their base year values, the negative competitiveness effect dissipates (Figure G.10). The stimulus to

RUK trade is sufficient to outweigh the negative external competitiveness effect over time, and GDP rises above base in the long-run (Figure G.8).

As with the RUK economy, the increase in GDP is strongest for this scenario relative to the other model set-ups. The boost from interregional trade is strongest for the Quasi I-O scenario, due to the absence of a long-run negative competitiveness effect in the RUK economy and the associated strongest increase in RUK GDP for this scenario. Furthermore, the impact of the negative competitiveness effects associated with rising wages are least strong in this scenario in Scotland relative to the Bargaining and Flow Migration cases, since real wages remain fixed.

Although the overall impact of the RUK export shock is an increase in long-run GDP in both regions, the effects of the stimulus are much slower to materialise in the Scottish economy compared with the RUK. In period 10, the relative increase in RUK GDP is 42.90% of its long-run value. In contrast, Scottish GDP in period 10 is just over 6.22% of its period 75 value. This is attributable to the interregional transmission mechanism between the two economies and, in particular, the effects of the presence of supply-side constraints. The RUK economy receives an initial demand injection from an increase in ROW manufacturing exports, but supply constraints limit the impact in the short- and medium-run. The direct impact of the ROW demand stimulus is sufficient to dominate the adverse supply reaction in the RUK, however, leading to an overall increase in GDP, even in the short-run (Figure G.1)[18]. Over time, as capacity constraints relax, the full effects of the demand shock are transmitted to the wider RUK economy. The Scottish economy, in contrast, does not receive the immediate ROW demand stimulus. Rather, the increase in demand for the Scottish economy is generated indirectly from an increase in the demand for intermediate and final goods from the RUK, and these effects take time to feed through. The differing source of the shock results in a very different adjustment process compared with that of the RUK. In fact there are significant adverse price implications for the Scottish economy in the short and medium run, which contribute to a fall in Scottish GDP relative to base until period 8. As UK activity rises

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[18] This is true for the RUK economy across each of the labour market scenarios.

following the shock and the price of UK intermediate goods increases, this feeds through to higher prices in the Scottish economy (Figure G.9), and an associated negative impact on external competitiveness and ROW exports for Scotland (Figure G.14). Although there is a demand stimulus in Scotland via the expansion in RUK output and the increase in Scottish exports to the RUK (Figure G.13), this is insufficient to outweigh the negative impact of the price effects on overall GDP. This holds true for all the labour market scenarios in Scotland in the short-run (Figure G.8). As capacity constraints optimally adjust in the UK over time, the full effects of the improvement in demand are transmitted to Scotland via interregional trade linkages, resulting in a protracted adjustment period for the Scotland economy (Figure G.8).

The nature of the demand shock therefore has much more complex implications for the non-target region than straightforward I-O analysis would imply. Whereas under I-O analysis an increase in ROW exports for the RUK constitutes a pure demand shock, the active supply-side response embodied in CGE analysis means that the other-region effects are both demand and supply orientated, and this suggests that I-O analysis would provide a very poor approximation of the effects of the shock in the presence of a non-passive supply-side. Furthermore, the ability to analyse the period-by-period results reveals important insights about the adjustment process of the regional economies that are not uncovered by I-O analysis: in particular, whilst the long-run equilibrium outcome is a boost to GDP in Scotland, GDP is lower than base in the year following the shock, and for much of the Treasury's ten year time horizon for the evaluation of regional development policies.

3.3.3 Regional Bargaining: RUK economy results

The results from the Quasi I-O configuration serve as a useful benchmark against which the Bargaining and Flow Migration results can be compared. The introduction of bargained real wages, either without migration (the Bargaining scenario), or with migration (the Flow Migration scenario), reduces the size of the relative GDP stimulus in both the RUK and Scottish economies relative to the Quasi I-O case, as the responsiveness of wage rates gives rise to negative competitiveness effects that are maintained into the long-run (Figures G.1 and G.8).

In the case of the Bargaining scenario, the relative increase in RUK GDP is the lowest out of all the configurations, with the long-run change in GDP around 25% of the value of the GDP stimulus in the Quasi I-O scenario (Figure G.1). In this set-up, as in the previous scenario, the export stimulus increases the derived demand for labour (Figure G.4). With no interregional migration, real wages rise according to the wage bargaining relationship, reflecting the tightness of the regional labour market (Figure G.5). Commodity output prices therefore rise relative to base, as does the overall CPI (Figure G.2). This represents a significant negative competitiveness effect: real wages are 0.82% higher than base by period 75 (compared with no change in the Quasi I-O case) and economy-wide prices are 1.20% higher (compared with 0.03% in the previous scenario). Furthermore, whilst the negative competitiveness effect that occurred in the Quasi I-O case was a short-run and indirect effect, in the Bargaining set-up the effect remains significant for the duration of the simulation period, and operates directly through the labour market.

As a result of the reduction in RUK competitiveness relative to that in the Quasi I-O case, the increase in RUK exports to the ROW is lower (ROW exports increase by 3.85% relative to base by period 75 in the Bargaining scenario, compared with 6.43% under the Quasi I-O case) (Figure G.7). This is reflected in the weaker GDP stimulus under this market set-up, and accounts for a more subdued increase in total RUK employment relative to base over the period (Figure G.4).

3.3.4 Regional Bargaining: Scottish economy results

The presence of bargained real wages similarly reduces the GDP stimulus in the Scottish economy compared to the effects under the Quasi I-O scenario. Over time, as output expands and the derived demand for labour increases in Scotland, real wages are bid up (Figure G.12). This reduces Scottish competitiveness relative to the Quasi I-O case, leading to a larger fall in ROW exports (Figure G.14). Furthermore, the reduced GDP stimulus in the RUK economy – similarly associated with reduced RUK competitiveness as a result of the responsiveness of RUK wages – means that the increase in RUK intermediate and final demands for Scottish exports is also relatively weaker under this scenario compared with the Quasi I-O case. These effects together contribute to a significantly lower GDP stimulus for Scotland in this case relative to the Quasi I-O scenario. By period 75, GDP is 0.08% higher relative to base in this scenario, compared with 0.98% in the Quasi I-O case.

3.3.5 Flow Migration: RUK economy results

The demand shock results in a relative increase in RUK activity compared to base when migration is introduced (together with bargained real wages), but the relative increase in GDP is also less than that of the Quasi I-O case. In the Flow Migration scenario, the source of the long-run boost remains the same as in the previous two set-ups: higher export demand increases traded sector outputs, and the boost in activity feeds through to the wider economy.

In this model configuration, the responsiveness of the real wage works to reduce external competitiveness as activity rises, as in the Bargaining scenario. The introduction of migration, however, lessens this adverse effect to some extent. Immediately following the demand shock, the prices of value-added and commodity outputs rise in the traded sectors, and economy-wide prices increase relative to base (Figure G.2). As in the Bargaining scenario, the resultant increase in output and the reduction in unemployment mean that real wages are bid up (Figure G.5).

Here, as in the Bargaining scenario, the increase in real wages and consumer prices brings about a negative competitiveness effect, offsetting to some extent the demand shock (albeit that the overall increase in economic activity remains positive, with the negative supply-side effect from the wage increase being small relative to the demand injection). However, the allowance for migration means that, following the shock in the RUK economy, some of the labour supply migrates away from Scotland and into the RUK economy, where the unemployment rate is relatively lower and real wages relatively higher. Although there remains a UK-wide labour market constraint (zero net migration is assumed in the UK overall), there is therefore some easing of the labour market constraints in the RUK, but at the expense of a contraction in the Scottish labour supply. Thus the presence of interregional migration, and the increase in the labour supply in the RUK, works to mitigate the increase in RUK real wages in the long-run (Figure G.5) compared with the Bargaining scenario. However, the effects are muted: by period 75, real wages are 0.76% above their base values in the Flow Migration scenario, compared with 0.82% in the Bargaining case. The increase in nominal wages is therefore less in the Flow Migration case in the long-run: nominal wages are 1.94% higher than base in period 75, compared with 2.03% in the Bargaining case (Figure G.3). The presence of migration therefore reduces the loss in price competitiveness of RUK exports. RUK exports to the ROW are 3.95% higher, compared with 3.80% for the Bargaining scenario (Figure G.7). As a result, the long-run GDP increase under the Flow Migration scenario is greater than under the Bargaining scenario, but still lower than under the Quasi I-O case, where the real wage increase is zero, the price increases more subdued in the short-run (and zero in the long-run) and the negative competitiveness effect least prevalent (Figure G.1).

3.3.6 Flow Migration: Scottish economy results

In contrast to the effects on the RUK economy, the introduction of interregional migration makes for an overall reduction in long-run GDP relative to base for Scotland (Figure G.8). By the end of the simulation period, Scottish GDP is 0.86% below its base value. This compares with a relative increase in GDP of 0.98% for the Quasi I-O scenario and 0.08% for the Bargaining closure.

As in the Bargaining scenario, the Scottish economy experiences an increase in export demand from the RUK economy (Figure G.13). But the presence of migration works to counteract the Scottish stimulus in the Flow Migration scenario. Owing to the direct effects of the demand shock in the RUK, the increase in the real wage over time and the proportionate rise in employment relative to base are stronger in the RUK compared with Scotland. These changes in the Scottish/RUK unemployment and real wage ratios mean that some of the population flows into the RUK economy, and the Scottish economy experiences an adverse supply shock in the form of a reduced labour supply. In period 75, the Scottish population is 2.58% lower relative to base[19].

The increase in demand for Scottish goods from the RUK economy, combined with reduced population, means that there is still upward pressure on commodity output prices and overall CPI in the Scottish economy (Figure G.9). As in the RUK economy, this causes a detrimental effect on Scottish exports to the ROW (Figure G.14). In contrast to that of the RUK, however, the overall effect of the demand disturbance in this scenario is a long-run fall in GDP and employment relative to base (Figures G.8 and G.11). The source of the different outcomes is the effect on the regions' labour supply. When both regions have bargained real wages – without migration – each region experiences an increase in output and employment in the long-run. This is because the reduced ROW competitiveness – brought about by the responsiveness of real wages – is offset by the demand stimulus. The introduction of migration, however, results in an increase in the labour supply in the RUK and a reduction in the Scottish labour supply, and this additional supply-side constraint exacerbates the loss of competitiveness in this region.

3.4 CGE results: the impact of a regional demand stimulus on the Scotland-RUK CO_2 'trade balance'

The CGE simulation results of the demand stimulus discussed above can be used to examine the resulting effects on the pollution content of trade flows between Scotland and the RUK. This is done by recreating the interregional environmental I-O table for each period, computing the Type II inverse and applying the base year Leontief output-pollution coefficients.

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[19] Lisenkova et al. (2007) explores the macroeconomic impacts of demographic change in Scotland in a CGE context, and similarly finds that a tightening of the labour market will have adverse consequences for employment, growth and competitiveness in the Scottish economy.

Table F.7 shows the new environmental ‘trade balance’ between Scotland and the RUK for the Quasi I-O scenario, in period 1. Table F.8 shows the percentage change in period 1 following the shock compared with the Type II base given in Table F.1. The key aspect to note is that there are changes throughout Table F.8, in contrast to the I-O case (Table F.5) where only emissions in Scotland and RUK supported by ROW export demand changed. This reflects the fact that both prices and quantities are determined endogenously in the CGE framework, and that prices also change due to the presence of an active supply-side. This in turn induces further changes in local intermediate and final demands, as well as export demand for production in both regions, and both elements of Scotland’s CO_2 ‘trade balance’ (emissions embodied in interregional exports and imports to and from RUK) change. In this first period, Figure G.6 illustrates that RUK exports to Scotland fall initially, due to the increase in RUK prices, and this is reflected in the reduction in RUK emissions supported by Scottish final demand. Scottish exports to the RUK, on the other hand, rise from the outset as shown in Figure G.13 (in order to meet increased intermediate and final consumption demand), as do Scottish emissions supported by RUK final demand. The composition of trade flows between the regions also changes. This is due to the exogenous demand stimulus being focussed in the RUK 'primary, manufacturing and construction' sector, with the corresponding Scottish sector receiving the largest relative demand stimulus from RUK (1.62%). The electricity, gas and water supply sector receives the smallest RUK export demand stimulus in period 1 (0.70%). However, given the relative emissions intensity of this sector, the emissions in this sector supported by RUK export demand to ROW rise more than proportionately (2.81%).

Table F.9 shows the adjustment of Scotland’s CO_2 ‘trade balance’ with RUK over the 75 periods modelled for the Quasi I-O case. As both Scottish imports from and exports to the RUK rise, the positive impact on the ‘trade balance’ narrows, but Scotland’s CO_2 deficit with the RUK is reduced overall in each of the three cases, due to the larger increase in Scottish exports to the RUK and the change in the composition of interregional trade.

In terms of CO_2 emissions, the Quasi I-O case again comes closest to the I-O case by period 75 (see Tables F.5 and F.10). However, this model configuration may overestimate the boost to activity in response to the initial demand stimulus, due to the lack of supply-side constraints. In the Bargaining case, where real wages change in response to the shock, reducing the size of the GDP stimulus in both Scotland and RUK, Scottish imports from the RUK fall throughout the period modelled, while exports to the RUK still increase (though to a lesser extent than in the Quasi I-O case) – see Figure G.6. This is also true for the Flow Migration case, where the presence of migration works to counteract the extent of the stimulus to overall activity in Scotland (Figure G.8). Tables F.11 and F.12 show the CO_2 'trade balance' in period 75 for these two scenarios. In each case, the change in total regional and national emissions is considerably lower than in the I-O or Quasi I-O cases (Tables F.5 and F.10), as would be expected, given the more limited increase in activity.

In terms of the UK's commitment to reduce CO_2 emissions generation, the Flow Migration outcome is the most positive, with the lowest increase in national CO_2 generation (0.98% compared to 1.02% in the Bargaining case and 3.06% in the Quasi I-O case). There is a reduction in total Scottish emissions in this case of 0.77%, reflecting the contraction in activity in the Scottish economy, as explained above.

However, the greatest reduction in Scotland's CO_2 'trade balance' with RUK is observed in the Bargaining case. In this set-up, the pollution embodied in exports to the RUK rises by more (1.74%) in Period 75 than in the Flow Migration case (0.61%), which offsets a slightly bigger reduction in emissions embodied in imports to Scotland from RUK.

However, as noted above, one of the key benefits of using CGE analysis to inform policy is that the adjustment path of the economy in response to a given disturbance is revealed. With I-O analysis, in contrast, there is no explanation of the transition process from one equilibrium to another. The CGE results show that the movement to long-run equilibrium is slow, and full convergence occurs beyond the UK

Treasury's stated ten-year time horizon for the analysis of regional policies. Table F.13 shows the change in the CO_2 'trade balance' at summary time intervals over the seventy-five year period modelled, for each of the CGE labour market scenarios. While the ranking of the three configurations in terms of the size of the CO_2 trade balance is the same throughout the whole period, the divergence between the results for each scenario changes over time. Figure G.15 illustrates that the absolute change and level of the CO_2 trade balance is very similar under the three CGE model configurations during the policymakers' ten-year time period of interest, and Figure G.16 shows the percentage change in the pollution embodied in gross interregional trade flows between Scotland and RUK. However Figures G.6 and G.13 show that only a portion of the adjustment in interregional trade flows occurs within this timeframe, and that in the Quasi I-O case there is a qualitative shift for the RUK region, with the change in RUK exports to Scotland becoming positive after around 17 years. Therefore, without access to a full CGE analysis, or relying only on the type of I-O results computed in Section 2.3, policymakers concerned with the impact of changes in economic activity on consumption-based measures of UK emissions would be lacking important information[20]. The above results, however, are qualified on a number of counts, primarily in relation to data constraints, and are therefore intended to be illustrative in nature.

4. Summary and conclusions

At present, there is much emphasis at a regional, national and international level on measuring and assigning responsibility for pollution using consumption-based methods, such as carbon footprints. One contribution of this paper is that it links the I-O accounting analysis of the crucial issue of the pollution embodied in trade flows and CGE analysis, which, to date, has not been used to analyse the CO_2 content of inter-country or interregional trade flows. The I-O methodology is undoubtedly a

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[20] Due to lack of appropriate data, a full consumption-based measure of UK emissions (including pollution embodied in imports from the ROW) is not carried out here. Instead, the focus is on allocating total UK emissions (under the production accounting principle) to regional consumption demands (using the consumption accounting principle). However, the same broad lessons learned from the analysis presented here would apply to a full consumption-based accounting and modelling exercise.

powerful technique for considering CO_2 trade balances. However, in this chapter I argue that, where there is a requirement to model the impact of marginal changes in Economic activity on variables such as interregional pollution spillovers, I-O modelling frameworks of the type outlined in Section 2 are of limited use due to their restrictive assumptions. In contrast, the CGE model of Section 3 retains the key strengths of the I-O model in terms of its multi-sectoral, system-wide framework, but also allows for more theory-consistent modelling of demand- and supply-side behaviour. I demonstrate this argument by simulating a positive regional demand stimulus in the UK using both an I-O and a CGE framework, and compare the impact of the shock on key economic variables and the CO_2 ‘trade balance’.

In the I-O analysis, the export demand stimulus to the RUK 'primary, manufacturing and construction' sector leads to an increase in GDP in the RUK, but also in the non-target region, Scotland. The indirect stimulus to the Scottish economy is driven by an increase in demand from the RUK for intermediate inputs. In the absence of supply-side constraints in the I-O framework, the rise in activity in both regions occurs without any change to prices that may lead to negative competitiveness effects. Thus, the full extent of the initial increase in RUK export demand is reflected in the new equilibrium. In terms of the emissions spillovers between the regions, only one aspect of the CO_2 trade balance is affected - Scottish emissions attributable to RUK final demand - since this is the only change in final consumption activity.

For the CGE analysis, the results are quite different, and the period-by-period results reveal important information about the adjustment process of the economy. Following the demand stimulus in the RUK, in the short-run, capital stocks are fixed, as is population in each region an in the national economy. Unlike in the I-O case, there is not sufficient excess capacity in the economy in order to meet the increase in demand at the outset. In all of the labour market scenarios considered, capital stocks adjust over time through investment, but the adjustment (or not) of regional labour supplies varies, as does the treatment of labour costs. However, in each of the configurations, total factor costs increase in the RUK regions, at least via an increase in capital rental rates, and in two scenarios via an increase in both real and nominal wages also. Consequently, negative competitiveness effects mean that the full extent of the demand stimulus is not realised initially. In the longer-run, as capital markets (and in one scenario the labour supply) adjust, the negative competitiveness effects ease and effects of the demand stimulus feed through to the RUK economy more fully. In Scotland, there is also a positive demand stimulus, caused by an increase in RUK demand for Scottish intermediate inputs. However, the Scottish economy also imports from the RUK, and so the rise in RUK prices contributes to a negative supply shock in Scotland. Furthermore, the indirect demand stimulus puts upward pressure on capital rental rates in Scotland. As a result, negative competitiveness effects persist in Scotland until supply-side constraints adjust in both regions.

The results demonstrate that in the I-O analysis, the export demand stimulus is a pure demand shock, which directly affects RUK activity and indirectly affects Scottish activity. In contrast, in all three of the CGE simulations, the presence of an active supply-side means that in each region the effects of the demand shock are both demand- and supply-orientated, and in Scotland the supply-side constraints dominate in the short-run, leading to an overall fall in GDP relative to the base. The CGE methodology has important implications for analysing the effects on interregional emissions spillovers. The price responsiveness of final demands means that the regional demand stimulus translates to a change in all elements of the interregional CO_2 trade balance. Thus by modelling both demand and supply-side behaviour in a more theory-consistent manner, the results reveal issues of potential importance to policy makers.

The results draw attention to the complexities associated with allocating responsibility across the UK regions for contributing to national emissions targets. This is particularly relevant in the context of UK devolution, where regional authorities such as the Scottish Parliament have limited powers to control emissions, especially with respect to changes in other-region demand. The analysis is therefore an important starting point for considering the potential for policy co-ordination constraints between the regional and national administrations with respect to environmental and energy policy objectives, and the appropriateness of the current devolution settlement in terms of energy policy instruments. The intention of the analysis is not necessarily to emphasise the quantitative results of the I-O and CGE simulations. Instead, the objective is to demonstrate the usefulness of CGE analysis in providing a more comprehensive approach to this particular regional policy issue: the impact of demand disturbances on interregional pollution spillovers. The finding that the CGE computational results have a greater analytical content than that of the I-O model is specific to the policy issue and the models considered in this paper. Nevertheless, the nature of the additional information content of the CGE results – in particular the ability to consider the adjustment process of the economy in response to a shock and to model the effects of different supply-side specifications of the results – help to justify the use of CGE models for the regional and national policy analyses that are central to this thesis. The overall aim of this thesis is to consider a range of regional and national policy concerns, and to provide a more comprehensive analysis of the issues than that currently available. The findings of this chapter demonstrate that CGE analysis is potentially a very useful framework for doing so.

The results are qualified in a number of respects. Firstly, the interregional I-O and SAM databases are based on estimated and experimental data, and this may distort the results of the simulations (see McGregor et al., 2008). Secondly, the 3-sector, 2-region aggregation of the model frameworks are likely to be too highly aggregated for detailed analysis of environmental policy issues. Thirdly, the source of the demand shock is not specified, nor are the potential public sector finance implications considered. Lastly, the impact of the regional demand stimulus on international pollution spillovers is not examined. Such issues provide avenues for future research.

Chapter 6

The Formation of a Domestic and International Market for UK Tidal Energy Devices and Technologies: Assessing the Demand-Side Implications for the UK Economy.

1. Introduction

In recent years, environmental obligations have strongly influenced UK energy policy decisions. The UK's commitment to the Kyoto Protocol and additional EU energy policy measures, which emphasise the need for a reduction in CO_2 and other greenhouse gases in order to address climate change, will likely require a significant reduction in UK energy consumption from fossil fuel sources. As a result, UK energy policy has focused on the commitment to reduce greenhouse gas emissions by 34% by 2020, rising to 80% by 2050[1].

A number of domestic concerns have also influenced current UK energy policy. The continuing depletion of UK oil and gas reserves has emphasised the security of supply of energy resources, and the risks associated with dependence on energy supplies that are concentrated in a few regions around the world. Furthermore, the UK faces significant reductions in its electricity generation capacity due to the closure of a number of existing coal and nuclear power stations[2]. Combined, these factors suggest that major changes in the composition of the UK's energy generation mix are inevitable, with a move in favour of a broad portfolio of generation techniques, and emphasis on electricity derived from local renewable sources with

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[1] Committee on Climate Change (2008) and the Chancellor of the Exchequer's Budget Statement (April 2009). The latter is available from http://www.hm-treasury.gov.uk/bud_bud09_speech.htm. The emissions targets are relative to a 1990 baseline (Department for Energy and Climate Change, 2009a).

[2] It is expected that the UK will need around 30-35GW of new electricity generation capacity over the next two decades due to the projected closure of some existing coal and nuclear power stations (Chancellor of the Exchequer's Budget Statement, April 2009. See Footnote 1 for source).

low carbon emissions[3], such as hydroelectricity, on- and offshore wind power, marine energies and biofuels. The commitment to renewable energy generation is reflected in the government's target for 15% of total electricity supplies to be generated from renewable sources by 2020[4]. The Renewables Obligation, which requires that licensed electricity suppliers in the UK source an increasing share of electricity from renewables, is the main mechanism for incentivising this growth[5].

Whilst wind power has been the prevalent renewable technology that has been developed in the UK to date, other renewable sources have also attracted significant investment and political support. One such energy is tidal power[6], for which the vast resource around the coast of the UK is ranked among the best in the world. It has been estimated that the UK resource amounts to around 50% of the European supply[7], and between 10-15% of the known world resource[8].

World-wide interest in tidal energy has increased in recent years, and this is particularly true for the UK, and there are an increasing number of prototype and commercial devices operating or due to be operationalised in UK waters. In May 2008, OpenHydro's 250kW tidal device installation near Orkney became the first device to be successfully connected to the UK grid, and the company plans to install an array of 1MW devices in the Channel Islands in 2009 (The Scotsman, 2008b).

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[3] A number of reports emphasise that future electricity generation across the UK is forecast to come from an increasing array of renewable sources. See, for example: Royal Society of Edinburgh (2006); Ault et al., 2006; Department of Trade and Industry (2006a, 2007b).

[4] Chancellor of the Exchequer's Budget Statement (April 2009): see Footnote 1 for source. This target is also in line with EU renewable energy policy: the EU directive on renewable energy states a target of 15% for the share of UK energy to be supplied from renewable sources (European Parliament, 2009).

[5] The Renewables Obligations for the UK regions are set out in Statutory Instruments for: Northern Ireland (Department of Trade and Industry, 2007c); Scotland (Scottish Parliament, 2008); and for England and Wales (Department of Trade and Industry, 2006c and Department for Business, Enterprise and Regulatory Reform, 2009). The current rate of the Renewables Obligation for England, Scotland and Wales is for 9.7% of electricity to be sourced from renewable energies in 2008/09, rising to 15.4% by 2015/16 (See, respectively: Department for Business, Enterprise and Regulatory Reform, 2009; and Scottish Parliament, 2008). For Northern Ireland, the present level is 3%, rising to 6.3% by 2012/13 (Department of Trade and Industry, 2007c).

[6] Department of Trade and Industry (2003b) identifies marine energy research as a priority area, whilst the government-sponsored organisation the Carbon Trust (2006) states that 'wave and tidal stream energy have the potential for bulk electricity supply in the UK'.

[7] Black and Veatch (2005a) and Sustainable Development Commission (2008).

[8] Carbon Trust (2006) and Black and Veatch (2005b).

SeaGen, a commercial scale tidal device developed by Marine Current Turbines, with a full operational capacity 1.2MW, has also recently been connected to the National Grid at Strangford Lough in Northern Ireland (Johnston, 2009). A number of other projects are in the planning or development stage: Scottish Power Renewables, part of Scottish Power, recently announced plans to install 60MW of tidal power in Scotland and Northern Ireland by 2011 (Scottish Power, 2008); Sea Gen Wales aims to commission a 10.5MW tidal farm by 2011/2012 (Partrac Ltd, 2009); and Atlantis Resource, backed by Morgan Stanley, hopes to install a large tidal farm of up to 500 tidal devices in the Pentland Firth seabed. The company is expected to lodge plans with the Crown Estate, who owns the seabed, for the initial installation of fifteen turbines by 2011 (The Scotsman, 2008a). In addition, a large number of companies are active at the testing stage.

An important part of the case for renewable energy is the UK-wide economic benefits that would be associated with the deployment of devices such as tidal turbines. Domestic expenditures on research and development, production, installation and maintenance of tidal turbine devices could provide an important demand stimulus for the local, regional and national economies. Furthermore, a key driver in developing the UK tidal sector is the economic gain that could flow from the export of tidal devices, technologies and expertise[9]. Significant worldwide tidal resources, including in Australia, Canada, France, Japan, Korea and the US, provide potential for industrial development of the UK tidal turbine sector on an international scale.

The local benefits of various renewable energy projects have been estimated for a number of UK renewable energy projects - most notably wind power developments - with these estimates often used to argue in favour of projects during the planning process. However, it is not always clear from publicly available documents how these impacts have been calculated (for example Lewis WindPower, 2004; Comhairle nan Eilean Siar et al., 2006, which relate to proposals for a wind farm on

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[9] The export potential of the tidal power industry has been identified by a number of individuals and organisations, including the House of Commons Economics Affairs Committee (House of Lords Select Committee on Economic Affairs, 2008).

the Isle of Lewis), making it difficult to compare and evaluate the results[10]. Numerous uncertainties are involved in estimating the potential effects of such projects, and the overall economic impact can be highly dependent on wide-ranging factors, including policy support and the availability of investment funds. As such, estimates of the impact of projects are frequently speculative in nature and/or based only on surveys and consultations with industry insiders. In some cases they attempt to quantify the local employment effects of domestic expenditures, though there are few economy-wide analyses, and, to my knowledge, no explicit assessments of the economic impact of the development of an export market for specific renewable energy technologies. For the UK tidal sector, as yet there are no formal estimates of potential job creation or economic impact assessments, and no estimates of potential export demand that could be associated with the development of the sector.

In this chapter, I use a twenty-five sector CGE model, UKENVI, to estimate the UK economy-wide benefit from a domestic and export demand stimulus to the UK tidal power industry. A similar CGE model has previously been used to estimate the impact of the construction, installation and maintenance expenditures for wave power on the regional economy of Scotland only (Allan et al., 2008b), though the study relates to domestic expenditures only. In this paper, I consider the impact of tidal devices on the national economy of the UK, and incorporate estimates of potential export demand. In doing so, I focus on the development of the tidal industry over the eighteen year period 2008 – 2025 inclusive, and draw on a range of estimates relating to: the tidal resource capacity in UK waters; the installation timepath for domestic devices; and the production and maintenance expenditures for domestic device installations. I use export data for the Danish wind turbine industry to infer the potential export demand for UK tidal turbines. At present, there are no examples in the literature of this kind of analysis relating to the impact of the development of a domestic and export demand for tidal turbine production. However, Perry (2008) presents a CGE application which is noteworthy in this context. The author considers the existence of a number of policies in place in the

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[10] Though one exception is O'Herlihy and Co. (2006), which provides an economic impact appraisal for windfarm constructions.

EU and the US to replace fossil fuels with biofuels, and analyses the potential for the Argentinean economy to respond to an increase in export demand for biofuel commodities (such as seed and vegetable oils). The analysis of this chapter and that of Perry (2008) therefore have similarities in that they both impose an exogenous shock related to a particular aspect of growth in the renewable energy sector within a CGE framework. In Perry (2008), however, the model characteristics, country of study, methodology for imposing the shock and other key issues are quite distinct from the research of this chapter. An overview of the Perry (2008) analysis is provided in Chapter 2, Section 4.1.

The paper is arranged as follows. I provide a brief introduction to the principle underlying tidal power extraction in Section 2 and an assessment of the capacity for tidal power extraction in the UK for the period 2008 to 2025 in Section 3. In Section 4 I describe the assumptions underlying the estimates of the magnitude and trajectory of the domestic and export demand stimuli that are applied to the UK tidal energy industry. In Section 5, I provide an overview of the UKENVI CGE model which is used in the analysis, and I present the simulation strategy in Section 6. In Sections 7 and 8, I discuss the results of the simulations and the policy implications of the research, respectively. Finally, I offer concluding comments and suggestions for future research in Section 9. All tables and figures relating to the analysis are presented within the text of this chapter, whilst the UKENVI model listing is presented in Appendix H.

2. The principle of tidal power extraction

Tidal power derives from the relative forces of the sun and moon on the earth’s waters. The gravitational pull of the sun and moon on the earth creates two 'bulges' in the ocean's surface - one on the axis directly aligned with the moon, the other on the opposite side of the globe. The rotation of the earth generates the rise and fall of these bulges. As the surface of the ocean is raised and lowered periodically, this results in two tides per day (high tide and low tide), which is the dominant pattern in most of the world's oceans.

The timing and magnitude of tides at any location depend, amongst other factors, on the changing positions of the moon relative to the earth, the effects of the earth's rotations, and the characteristics of the sea floor and coastlines. These factors therefore also result in a large variation in the energy that can be obtained from tides on a daily, weekly and annual basis. The stronger the tide, in terms of water height or tidal current velocities, the greater is the potential for tidal energy extraction. For example, when the sun and moon are in line, around the time of new and full moons, their gravitational attraction on the earth combine and cause a 'spring' tide, where high tides are higher and low tides lower, generating larger deviations in available tidal energy resources. When the sun and moon are positioned 90° from each other, near the time of the first and last quarter-moon phases, their gravitational attraction partially cancel each other out, pulling the water in different directions. This generates 'neap' tides, producing smaller deviations in available tidal energy resources. The combination of the spring to neaps cycle, along with other factors, (including the fourteen-day diurnal tidal cycle) results in a variability of tidal power potential throughout the months of the year. This tidal behaviour is easily predictable, suggesting that the exploitable resource could generate power for known and defined periods of time, providing an important advantage over other renewable energies with unpredictable energy provision, such as wind power.

Tidal technologies use this phenomenon to extract electrical energy. There are two basic methods for converting tides into power. Tidal stream (or tidal current) technologies involve converting the power of vertical water movements - propelled by tides - into electricity using tidal turbines. The second approach, tidal ranges, involves generating energy from the rise and fall of the water level between high and low tides, using tidal barrages or lagoons. These are similar in principle to hydroelectricity dams, in that they trap water during high tide before releasing it to turn turbines to generate electricity. Tidal barrages have already been tried and installed in a number of places, and whilst they have proved successful, their perceived high civil infrastructure costs and environmental impact, as well as a worldwide shortage of viable sites, mean that tidal stream turbines are the leading technology concepts at present. This is reflected in the high volume of tidal stream initiatives in the development stage in the UK relative to tidal barrage projects. Therefore, in this research, I focus on the demand for tidal stream devices only.

Tidal stream devices transform tides into energy by converting the kinetic energy of fast-flowing water into electricity in much the same way as wind turbines: underwater turbines use tidal forces to turn the blades of the device and generate energy, with zero carbon emissions. They are positioned in areas where tidal currents are strong and fast enough to produce such energy from the water flow, and can be installed either horizontally or vertically, via floating devices or systems that are secured directly to the seabed. Each turbine is connected to a main cable which transfers energy to a power station where it is converted into electricity on the national grid. The amount of energy extracted depends on the speed of the flowing stream and the character of the area that the moving water intercepts. This is similar to wind power generation, but given that water is 832 times the density of air, a tidal electricity generator can provide significantly more power at low tidal velocities compared with wind speed. In addition, the predictable nature of tidal energy means that the output of the devices would be able to offset or control variability across a broad portfolio of renewable generation techniques for the UK.

3. The capacity for tidal power extraction in the UK 2008-2025

3.1 The magnitude of the domestic resource

The features required for tidal energy extraction combine in a number of coastal areas of the UK, producing a vast amount of technically extractable tidal resource[11]. Several published studies assess the potential capacity of tidal energy for the UK. Across the studies, however, the estimates vary significantly due to discrepancies in the source data and geographical coverage, as well as differences in technical assumptions regarding calculation methodologies, tidal turbine performance, and the

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[11] Some potential tidal farm sites are subject to constraints and pressures due to other marine activities (e.g. the existence of established shipping lanes or active marine cables and pipelines). In this study, tidal resources which are located near to, and which are unlikely to be able to co-exist with, existing marine activities, are excluded from final estimates of the tidal resource.

potential to exploit resources in deeper waters. Full details of the methodologies followed are not always reported, making comparison particularly difficult.

In this analysis, I incorporate UK estimates from a number of key sources, which are summarized in Table 6.1. Black and Veatch (2004) estimates that there is around 18 TWh/yr of technically extractable UK tidal stream resource, and 12TW/yr of economically extractable resource[12], for what they have identified as the top forty tidal sites in the UK. To put this in context, the technically extractable resource amounts to around 5% and the economically extractable resource amounts to around 3% of UK electricity demand, and the economically extractable resource would require around 3000MW of installed electricity generation capacity[13]. Research by the Environmental Change Institute (2005) estimates an installed capacity[14] of 3,826MW for what they have identified as the thirty-five top locations of tidal resource in UK waters. Other studies indicate a higher resource availability: Bahaj and Myers (2004) estimate an installed capacity of 1,424MW in the Alderney Race alone, compared to the 248MW of installed capacity at the same site predicted by the Environmental Change Institute (2005) research; and the European Commission estimate the European tidal power capacity to be in excess of 12,000MW, with 8,900MW of the resource concentrated in the UK (Centre for Renewable Energy Resources, 2006).

At the time of writing, the most recent detailed estimate of the UK resource is by ABPmer (2007). This research quantifies a range of tidal energy resource capacities that could conceivably be achieved in the ten year period following publication of the report. These relate to an installed capacity estimate of 1,560MW, up to a *potential* installed capacity estimate of 9,553MW by 2018. The lower estimate imposes the

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[12] The technically extractable tidal stream resource is the amount of tidal energy that could be extracted without significant environmental effects, and without causing a reduction in the total tidal energy available for extraction (due to the positioning or density of tidal devices causing distortions in tidal flow patterns). The estimate of the economically extractable resource is distinguished from the technically extractable resource by taking account of the estimated cost of energy provision, according to existing technology at the time of the study (Black and Veatch, 2005a, 2005b).

[13] Based on the Black and Veatch's assumptions regarding the relationship between resource capacity and electricity yield.

[14] The definition of 'installed capacity' is taken to represent the available tidal resource that is feasible, given current technology and its ability to exploit resources at feasible water depths.

assumption that the upper limit for the size of a tidal farm is 30MW, on the basis that technical and economic factors could limit the capacity of farms to this size[15]. Estimates for the potential capacity, in contrast, relax this assumption on the basis that continuing technological improvements, creating higher capacity turbines, will enable greater resources to be extracted without risk of compromising the total resource capacity. This is in line with research by the British Wind Energy Association (2006), who estimates that, based on technologies at the time of publication of the research, tidal farm installations of over 30MW would be feasible from 2012 onwards. Moreover, recent announcements by tidal farm developers have included plans for tidal farms of 30MW and greater, including those by Atlantis Resource (the Scotsman, 2008a).

Table 6.1 UK economically viable resource estimates

Source	Resource (MW)	Notes
ABPmer (2007)	1,560 (lower estimate); 9,553 (upper estimate)	Estimated exploitable resource within the next ten years. Lower estimate based on 30MW farm size restriction; upper estimate relaxes this assumption.
Black and Veatch (2004)	3,000	Resource estimate of top 40 sites in UK.
Environmental Change Institute (2005)	3,826	Resource estimate of top 35 sites in the UK.
European Commission (1996)	8,900	Total European resource estimated at 12,500MW.
Salter (2005) and Mackay (2007)	Not yet quantified	Actual UK resource could be up to 20 times higher than current estimates based on the 'flux' method of resource calculation.

It should be noted that recent research (Salter, 2005; Salter and Taylor, 2007) has the potential to significantly alter the method by which tidal energy resource calculations such as those above are made, and may result in much higher predictions of energy yield. The aforementioned estimates are all based on the ‘Flux Method’ of calculation[16]. However Salter (2005) and Salter and Taylor (2007) suggest instead

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[15] This relates to the possibility that the cumulative impact of individual turbines operating in farm sizes greater than 30MW could work to counteract natural tidal flows to the extent that the overall resource in that area is compromised.

[16] The Flux Method is an extraction methodology independently developed by Black and Veatch and Robert Gordon University where the extracted energy is purely dependent on the incoming kinetic energy flux across the front cross-sectional area of a flow channel (Black and Veatch, 2004, 2005c).

that the total power in waves is not equal to the kinetic energy flux across a plane, as the ‘Flux Method’ presumes, but is related to the force created by the weight of water as a tidal peak applies pressure on neighbouring water, such that the vertical displacement of water becomes important. Taking this into account means that energy resource calculations could be significantly higher than those based on the ‘Flux Method’. MacKay (2007) provides analysis which largely concurs with these findings, and shows that the tidal resource is not limited to the kinetic energy flux across a plane, except in very specialized conditions, such as at the Straits of Gibraltar, but is in fact far in excess of this. The analyses have far reaching consequences for estimates of the calculation of tidal resources in the UK, and suggest that the actual resource could be up to twenty times higher than estimates based on the ‘Flux Method’[17]. These recent developments have not yet been incorporated into any large-scale detailed quantitative analysis of the UK tidal resource, nor have the methods been extensively assessed in peer-reviewed publications. As a result, the implications of this new research have not been taken into account in the resource estimate used in this analysis, though in later sections of this chapter, I do acknowledge the consequences of a more significant development of the UK tidal industry[18]. The implication of a greater resource would mean that the quantitative results of this study would be more substantial.

3.2 The timepath for the domestic installation of tidal turbines

The average UK tidal resource estimate across the studies (excluding the unquantified Salter, 2007, estimate), is a capacity of 5,320MW. However, the variability of the resource estimates across the studies suggests that a significant amount of uncertainty is associated with the calculations. In this paper, using these estimates for guidance, I assume that the total tidal resource capacity in the UK that could be extracted in the long-run is around the average estimate of 5,320MW, and that 3,000MW of this resource can feasibly be installed in UK waters during the

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[17] ABPmer (2007) and the Sustainable Development Commission (2007).

[18] Similarly, technological advances that allow the installation of larger arrays, or the use of tidal resources at greater depths than those estimated to be feasible for energy extraction, could increase the size of the domestic resource, and the potential economic impact of growth in the UK tidal sector.

eighteen year period from 2008 to 2025. It is this time period to 2025 that is considered in the simulations. Small arrays of tidal turbines (of around 5MW in size) are assumed to be installed in the initial years of development of the industry, with larger sized farms (of around 30MW in size) being installed from 2013 onwards. This is in line with the British Wind Energy Association's (2006) research which projects the likely size of tidal farm installations in the UK over time[19]. This amounts to a gradual increase in installations from 2008, with more rapid installation growth occurring in later years, as the industry gains strength. Figure 6.1 illustrates the assumed timepath for the installation of domestic devices that is required to reach a total capacity of 3,000MW of tidal power by 2025[20]. To put this in context, the 3,000MW capacity of tidal power by 2025 is just less than the installed capacity of wind power in the UK in 2008 (World Wind Energy Association, 2009).

Although there are a number of estimates available of the total tidal energy resource in the UK, there are few attempts to consider what might be a feasible installation timepath for tidal energy devices in the UK to exploit this resource over the medium or longer run. The Carbon Trust (2006) estimates that up to 2,500MW of tidal stream capacity could be installed in the UK by 2020. I use this installation timepath to inform the analysis. However, I extend this period so as to allow for the potential economic impacts of an export market for UK tidal turbines, which is likely to be slower to develop than that of a domestic market (see Section 4.2). I therefore consider an eighteen-year deployment timepath for the period 2008 to 2025. I assume that 3,000MW of domestic tidal energy installations can occur during this time, with significant export demand also developing in the later years of this period. To justify this assumption, I also draw on the deployment timepath for other emerging renewable technologies, in particular that of the growth in domestic

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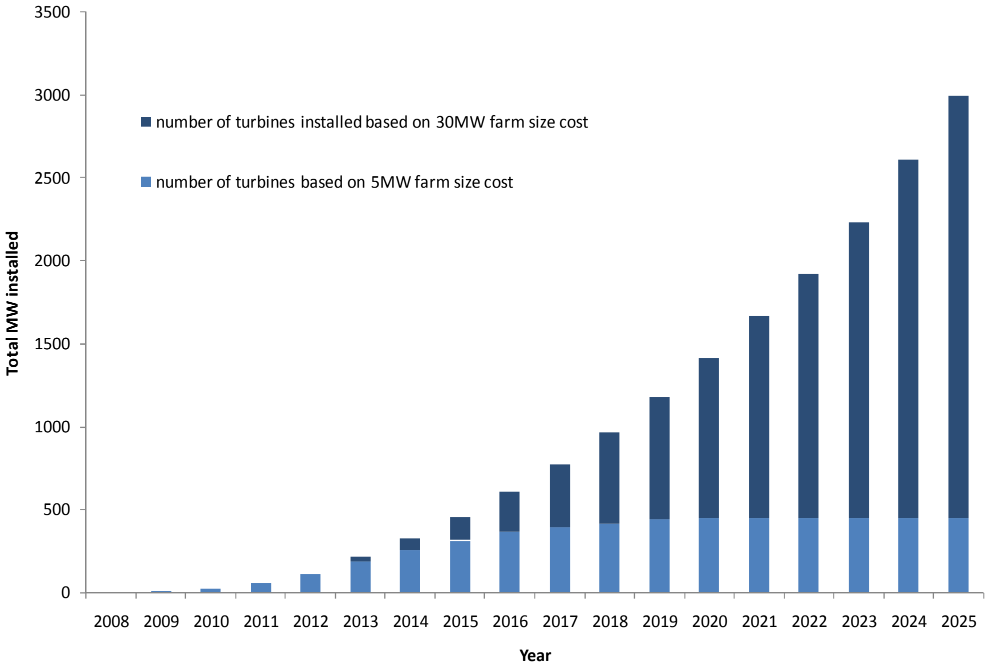
[19] The British Wind Energy Association (2006) estimates that tidal farm installations in the years up to 2010 will be of prototype or 'small array' size (up to 5MW), whilst larger tidal farm developments of 30MW or greater will be feasible from 2012 onwards.

[20] I do not explicitly take into consideration the environmental implications of the timepath and magnitude of the assumed tidal device installations. Several studies have considered the environmental implications of tidal electricity generation techniques, including the Strategic Environmental Assessment (Scottish Government, 2008b). The report suggests that up to 2,600MW of wave and tidal power capacity could be installed in Scottish waters alone by 2020 with generally minor effects on the environment.

capacity for the onshore wind industry in Germany and Denmark since their inception. In line with the expansion of the onshore wind industry in these countries, the UK tidal energy industry is assumed to expand gradually from a small base, before market confidence is developed, and with significant installations only made in the later years of the 18-year simulation period. The assumed installation timepath for tidal devices in UK waters is shown in Figure 6.1.

Figure 6.1 Timepath for UK tidal turbine installations 2008 to 2025 (MW)



A longer-term analysis would be useful for policy-making, however, there are a number of uncertainties regarding estimates of: (i) longer-term estimates of feasible installation rates for tidal devices; (ii) the exact size of the extractable tidal energy resource in the UK; (iii) tidal turbine expenditures relating to production, installation and maintenance of equipment; (v) the size of the potential export market for tidal devices; and (vi) the extent of policy support to encourage the development of the tidal sector as a whole, for example. These issues are likely to change significantly over time, which could limit the usefulness of and confidence in longer-run results. Furthermore, over time there may be learning effects, increasing returns to scale and/or economies of scale to consider, given the emerging and capital-intensive nature of the industry, and it may be interesting to capture such phenomena in a longer-term analysis. Chapter 8 considers the potential for incorporating such effects in further analyses. In this chapter, I aim to describe the potential short and medium run effects associated with growth in the tidal energy sector, based on resource and cost data available at the time of the study.

3.3 The geographical concentration of the UK tidal resource

The conditions required for tidal power generation are distributed unevenly across the regions of the UK (Environmental Change Institute, 2005). Many of the strongest tidal currents are located in shallow waters or through narrow channels that connect large areas of water, and the sites identified as containing the most powerful resources are concentrated in the North of Scotland around the Pentland Firth. As such, the Scottish economy, which contributes around 8% of UK GDP[21], is estimated to have between 38% and 68% of the total UK resource[22]. Significant potential has also been identified in Strangford Lough in Northern Ireland, Anglesey and Pembrokeshire in Wales, and the Bristol Channel and Alderney in England. Figure 6.2 illustrates the average tidal power around the coast of the UK, showing that areas of highest energy resource are concentrated in a limited number of sites. Figure 6.3 illustrates the UK sites that have been identified as suitable for tidal farms.

The uneven distribution of tidal resources implies that the impact of the expenditures associated with tidal device installations, and the potential for economic development, will differ across areas of the UK. In this paper, I abstract from consideration of the potential regional impacts, and focus on the effects on the UK as a whole[23]. However, in Section 8, I do discuss the policy implications of this issue and the potential impact on policy co-ordination efforts between the Scottish and UK governments, in light of the partially devolved responsibilities for energy policy.

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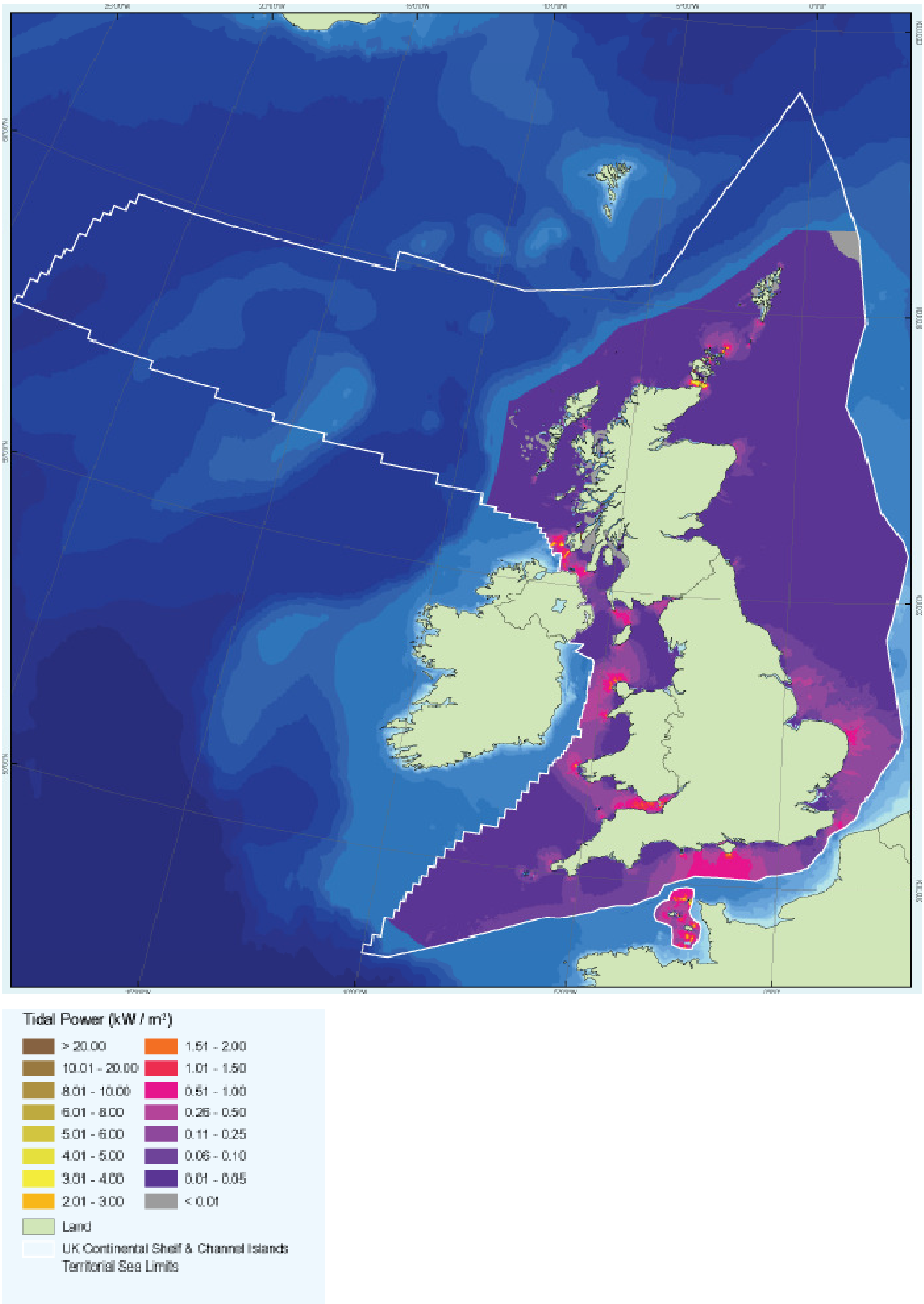
[21] Data sourced from Regional Trends (2009), Office for National Statistics, available at http://www.statistics.gov.uk/downloads/theme_compendia/Regional-Trends-41/RT41-Front.pdf.

[22] The Sustainable Development Commission (2007) and ABPmer (2007), respectively.

[23] Allan et al. (2008b) assesses potential regional economic impacts associated with developments in the wave energy industry in Scotland.

Figure 6.2 Average tidal power resource in the UK



Source: Department for Business, Enterprise and Regulatory Reform (2008).

Figure 6.3 Potential tidal farm sites in the UK

🟦 Tidal stream resource

Source: Sustainable Development Commission (2007)

4. Estimating the domestic and international demand stimuli

4.1 Domestic expenditure

The extent of the stimulus to UK demand that derives from the establishment of domestic tidal turbine farms will depend on the expenditures associated with the construction and operation of the turbines. There is considerable uncertainty about the costs, which will likely be site-specific and determined by the type of technology used. In calculating the expenditure associated with the production, installation and operation and maintenance of a generic, 1MW tidal turbine, I draw on several detailed costs estimates, including those of:

(i) Binnie, Black and Veatch (BBV) (2001). This study estimates the costs of a conceptual tidal turbine design developed by Marine Current Turbines Ltd for a proposed demonstration plant tidal power installation in Devon, and provides costs estimates based on 1MW, 5MW and 30MW tidal farms. The Department of Trade and Industry commissioned BBV to independently examine the costs of the project.

(ii) The Electric Power Research Institute (EPRI) (2006, 2008). The EPRI is a non-profit organisation, whose North American Tidal Stream Energy Conversion Project (TISEC) has been set up to consider the feasibility of tidal power in various locations in North America. The EPRI (2006, 2008) reports assess the costs of pilot and commercial tidal devices for several sites in North America, and the cost calculations are based on the manufacturing specifications of the UK SeaGen tidal device (installed in Strangford Lough, Northern Ireland).

(iii) Department of Trade and Industry (DTI) (2007a). This study compares the economics of two types of tidal turbine devices: a fixed turbine device, and a variable pitch turbine that rotates to face directly into the tidal flow. The assessment includes cost estimates for each device, and recommends that the fixed pitch device is competitive and most worthy of further consideration.

These studies give a good indication of the capital and maintenance expenditures that would be associated with growth in the domestic tidal energy industry. For the simulations, I use a combined average of the independent estimates as a proxy for the expenditures associated with a generic, 1MW tidal device. Table 6.2 summarises the expenditure estimates for each of the independent studies[24].

In addition to these costs, there will also be expenditures associated with the decommissioning of devices. Each device is assumed to have a lifetime of twenty-five years (Department of Trade and Industry, 2007a). Since the scope of this analysis covers an eighteen-year simulation period, I exclude decommissioning costs from the domestic expenditure calculations. However, current estimates indicate that decommissioning costs will be small relative to initial capital costs (Carbon Trust, 2006)[25].

Table 6.2 Cost estimates for a 1MW tidal turbine device (£)

	based on 1MW farm		based on 5MW farm		based on 30MW farm	
	capital	O&M	capital	O&M	capital	O&M
BBV (2001)	2,162,679	60,545	1,328,409	45,673	1,108,753	41,133
EPRI (2006, 2008)	2,965,735	-	-	-	1,238,598	82,077
DTI (2007c)	-	-	-	-	1,250,000	48,967
Average estimate	2,564,207	60,545	1,328,409	45,673	1,199,117	57,392

Note (1): Operation and maintenance (O&M) costs are annual estimates

Note (2): the EPRI estimates are converted from dollars to pounds sterling using the three month average exchange rates as at April 2009 ($1=£0.62740)

For some of the estimates in Table 6.2, tidal turbine costs vary depending on the size of tidal farm installation, with smaller (1MW and 5MW) farms having a higher per-

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[24] These are projected costs, and there is a high degree of uncertainty attached to them (for example, technological improvements could reduce costs significantly over time). Each of the cost estimates is reported in nominal prices. Given the cost uncertainties, and the low level of inflation during the time period of concern, I do not use inflated costs in the analysis. However, doing so would have a negligible impact: this would add around 0.35% to the estimated size of the domestic expenditure stimulus by the year 2025, for example (using HM Treasury's latest UK deflator series; available at http://www.hm-treasury.gov.uk/data_gdp_fig.htm).

[25] Department for Trade and Industry (2007a) estimates a decommissioning cost of £25,000 per device.

MW cost than that of larger (30MW) farms. For the aggregate domestic expenditure estimates used in this analysis, I assume that the installation costs correspond with the deployment of smaller (5MW) tidal farms in early years, with larger (30MW) farms being installed in later years. Figure 6.1 illustrates the assumed installation timepath of the different sizes of tidal farms in the UK. The aggregate expenditure calculations used in the simulations correspond with this projection.

4.1.1 Sectoral distribution of the domestic expenditures

The impact of the demand shock resulting from the domestic market for tidal power will be felt across a number of sectors in the UK, since the construction, operation and maintenance of tidal devices involves inputs from a number of sectors. The capital costs include: the cost of the device itself (material and component inputs, fabrication, and manufacturing labour); installation costs; foundation or moorings costs; and the costs of grid connection (including electrical cables and switchgear). Similarly, the operation and maintenance cost can be broken down into expenditures on insurance and financial services, and public administration costs associated with seabed rents. I therefore consider a detailed breakdown of the cost estimates so as to represent the sectoral effects of the demand stimulus. The Binnie, Black and Veatch (2001) and EPRI (2006, 2008) studies provide detailed sectoral breakdowns of the different categories of expenditure for tidal power devices. I calculate the percentage share of the total capital or operation and maintenance costs for each category of expenditure, for each of the studies. I then use an average of these shares to disaggregate the domestic expenditures across the UK sectors in this study[26]. Each of the categories of expenditure are then assigned to an appropriate Standard Industrial Classification (SIC) (92) for the UK economy (see Table H.1, Appendix H), and allocated to the appropriate sector of the UKENVI model. Tables 6.3 and 6.4 provide the sectoral distribution of the capital and operation and maintenance components of the domestic expenditures, respectively.

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[26] A small degree of reorganization of the categories of capital and operational expenditures was necessary to harmonize the cost data across the studies.

Table 6.3 Sectoral share of capital expenditure.

Category of capital expenditure	% share of total capital expenditure	UKENVI sector number	UKENVI sector name
Power conversion system	16.9	11	Electrical & electronics
Mono-pile/structural elements	10.4	10	Other machinery
Subsea cable cost	1.7	11	Electrical & electronics
Assembly & transport	1.1	14	Construction
Mono-pile/turbine installation	28.3	11	Electrical & electronics
Subsea cable installation	19.4	14	Construction
Onshore items & grid interconnection	1.4	11	Electrical & electronics
Overheads and other items	20.8	14	Construction

Table 6.4 Sectoral share of operation and maintenance expenditure.

Category of O&M expenditure	% share of total O&M expenditure	UKENVI sector number	UKENVI sector name
Other O&M	41.7	14	Construction
Seabed rent	3.2	18	Public administration & education
Annual insurance cost	55.1	16	Communications, finance and business

4.1.2 The extent of local sourcing

The share of the tidal device costs that is actually spent in the UK will depend on a number of factors, including: the existence of indigenous firms with sufficient knowledge and experience of the manufacturing and installation process; the rate of technological development relating to device design and construction, either via learning rates or the attainment of economies of scale in production; the supply of local, suitably skilled labour; the existence of a components supply chain in the UK, and the capacity for local firms to meet increases in demand. Such factors will likely be greatly influenced by the extent of government support provided in order to promote a strong research and development base in the UK and to establish an indigenous supply chain and strong research and development base. Such issues will directly impact how much of the inputs are sourced in the UK, rather than abroad[27].

Some aspects of early tidal power developments have been outsourced: for the SeaGen tidal energy turbine installed in Northern Ireland in April 2008, British engineering firms were contracted to build, test and monitor the turbine, whilst the components were manufactured in various locations in the UK and Europe and a Belgian firm was contracted to help in the deployment stage. Experiences from other renewable energy projects also suggest that some components may be imported: Lewis and Wiser (2007) note that out of the 889MW worth of onshore wind power installed in the UK in 2004, 0% of the turbine component parts were manufactured in the UK, and Allan et al. (2008a) find that the onshore wind industry has little ‘multiplier effect’ in the Scottish economy, due to the absence of established backward linkages. Recent anecdotal evidence for the UK economy suggests that the wind energy industry remains import-dependent, and is focused on turbine assembly, rather than the production of devices[28]. There is an argument that the UK missed an opportunity in developing a strong domestic industry in wind turbine production due to a lack of policy support[29]. The development of the sector could potentially be quite different in the presence of appropriate policy mechanisms. Since the Scottish and UK governments have already voiced their support for the industry, the prospects for the sector appear encouraging.

Already, there is a significant marine energy production capacity in the UK, and whilst there are, as yet, no detailed commentary or analyses regarding the potential degree of UK local sourcing of the component parts, there are indications that a

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[27] The Forum for Renewable Energy Development in Scotland (2005) considers the issue of skills shortages for the Scottish renewable energy sector, and finds that, at the time of publication, the issue is not a major constraint, and that the building blocks required to build a skills base for future requirements of the industry are already in place.

[28] For UK wind turbine manufacturer Windsave, a large share of their recent production work is for domestic installations, though a significant portion of the electronic component parts for the turbines are sourced from the Far East (Marine Current Turbines, 2008).

[29] Lewis and Wiser (2007) conduct a cross-country comparison of the policy support mechanisms that have been employed to support wind power industry development, and argue that other countries’ policy measures have been more successful at developing large indigenous wind turbine manufacturers, compared to the UK.

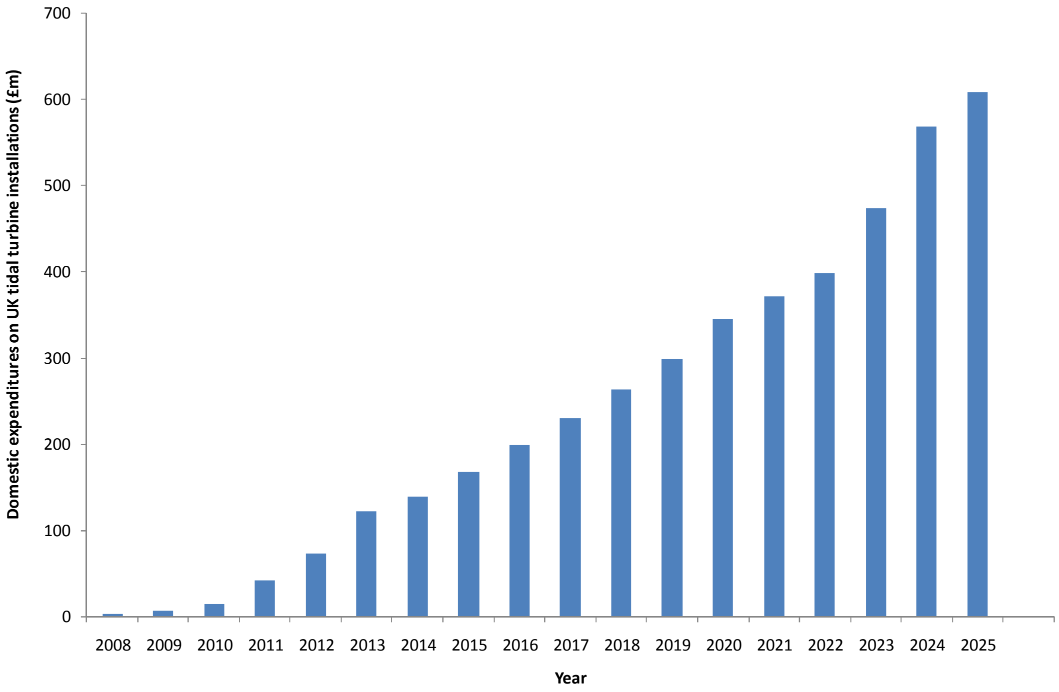
supply chain is already developing, at least in Scotland (Scottish Renewables Forum, 2007). However, since many tidal turbine technologies are in the early stage of development and production, and the parts are still specialised and not mass produced, there could be constraints in terms of lead times, costs, and the supply of skilled labour (NOF energy, 2008). As such, it is likely that at least some of the expenditure contracts associated with domestic tidal installations are awarded outside of the UK. To account for this, I adopt the assumption that only a share of the tidal turbine expenditures is spent locally. In particular, I assume that those inputs with a high electronic component (i.e. the power conversion system), have a high import propensity (such that 50% of the inputs are imported), whilst those expenditures which would intuitively be expected to be domestic-based (such as seabed rents, insurance and installation) have a low import propensity (from 0-10%). Other sectors are assigned a medium import propensity, of 25%.

Table 6.5 The assumed share of turbine inputs costs that are spent in the UK

Turbine component	Share of expenditure sourced locally
Power conversion system	50%
Mono-pile / Structural elements	95%
Subsea cable cost	75%
Assembly & transport	95%
Mono-pile / Turbine installation	95%
Subsea cable installation	95%
Onshore items & grid interconnection	75%
Overheads and omitted items	75%
O & M cost	90%
Rent, etc.	100%
Annual insurance cost	95%

Combined, the assumptions regarding: the average cost of a 1MW tidal device; the installation path of tidal devices provided in Figure 6.1; and the degree of local sourcing of the domestic expenditures, provide the total domestic expenditure timepath that is illustrated in Figure 6.4.

Figure 6.4 Domestic expenditures for UK tidal turbines



4.2 Estimating the export demand for tidal turbines

An additional part of the case for renewable energy is the potential for industrial development of the tidal turbine sector on an international basis. A strong domestic market for commercial scale tidal farms could be a precursor to and provide a firm base for exporting UK tidal devices, technologies and expertise. Around 10-15% of the worldwide tidal power resource is contained in the UK[30], with the remaining significant resource distributed across various sites in Australia, Canada, France, Japan, Korea and the US, amongst other countries. Figure 6.5 illustrates potential worldwide tidal energy sites.

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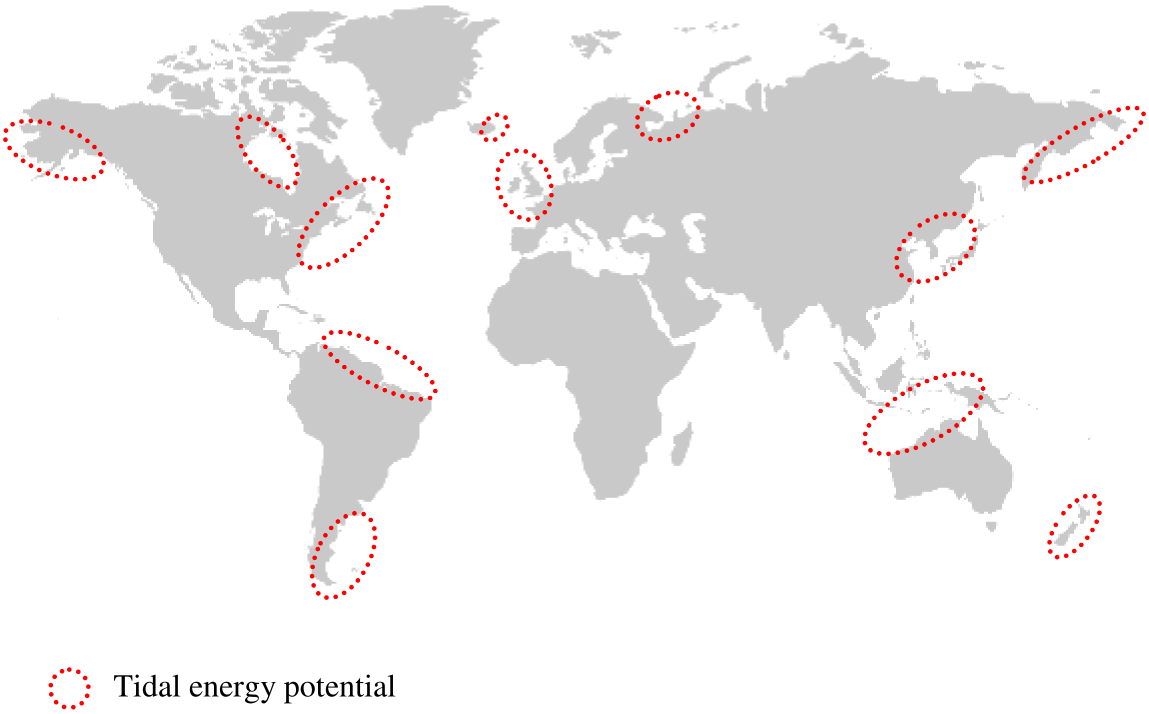
[30] Carbon Trust (2006) and Black and Veatch (2005b).

Figure 6.5 Known worldwide tidal energy potential



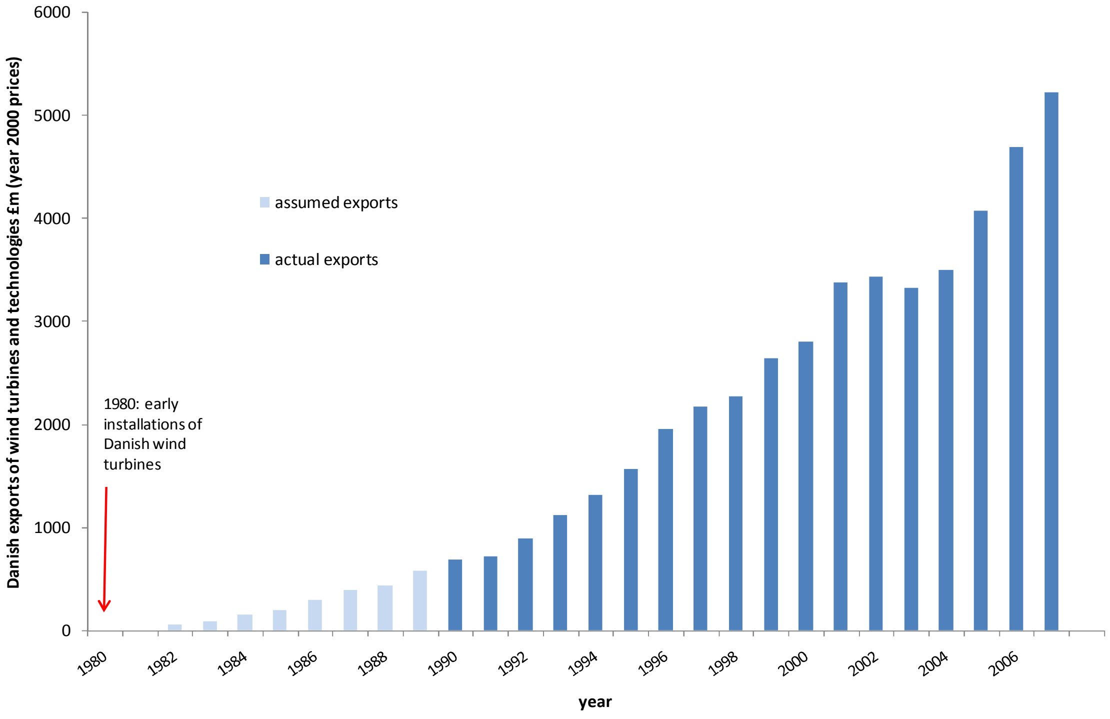
Source: Scottish Enterprise (2005)

A detailed enquiry into marine renewable energy as a whole, carried out by the House of Commons, highlighted that “the UK could create a new multi-billion pound domestic and export industry, employing thousands of people. The UK has the resource, the technology and the skills base; we have a unique opportunity to seize the lead and develop a world-class industry. We can no longer afford to neglect the potential of wave and tidal energy” (House of Commons Select Committee on Science and Technology, 2001, p.6). A number of other contributors have also noted the significant opportunity for UK firms to dominate the emerging worldwide market for wave and tidal energies (see, for example, Carbon Trust, 2006). One objective of this paper is therefore to consider the implications of an export shock to the UK economy that is directly associated with the development of an international tidal turbine market.

4.2.1 Estimating the size of the export demand for tidal devices

Section 4.1 of this chapter outlines the assumptions underlying the size and timing of the domestic demand shock, which are informed by several detailed analyses of the size of the UK resource and cost calculations and so forth. To estimate the potential magnitude of export demand for UK tidal turbines, I draw on the experience of the Danish export market for wind turbines. Data are available for Danish exports of wind turbines from 1990 onwards – around ten years after the first wind turbines were connected to the Danish grid (Figure 6.6). Much has been made of the successful export market for wind turbines that has become established in the Danish economy, and in this paper I aim to consider the impact on the UK economy if a similarly successful international market for tidal turbines were to develop.

Figure 6.6 Danish Exports of wind turbines (£m, 2000 prices)



Source: Danish Energy Agency[31]

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[31] The Danish wind turbine export data are compiled from three sources at the Danish Energy Agency: Danish Energy Agency (2008); the energy statistics database from the Danish Energy Agency's website (available at: http://www.ens.dk/en-US/Info/publications/Sider/Forside.aspx); and personal communication with Peter Dal, Senior Advisor, Climate and Energy Economy, the Danish Energy Agency, pd@ens.dk. The export data are available in Danish Krone, and have been converted to Pounds Sterling using the three month average GBP/Krone exchange rate as at February 2008.

Figure 6.7 illustrates the size and timepath for the export stimulus that is applied to the UK economy in the simulations. I assume that the UK exports of tidal turbines over the eighteen year simulation period 2009-2025 follow a similar path to Danish exports of wind turbines over the period 1980-2008 in absolute terms. That is, by 2025 the UK is assumed to be exporting around £5bn worth of tidal turbines, which is equivalent to the value of turbine exports in the Danish wind turbine industry in 2007[32]. Thus the main difference in the trajectory of the growth of the export sector for each country is the timepath: whilst the Danish export industry grew to its current size over a twenty-five to thirty year period, I assume that the UK export market grows much more quickly, over the eighteen year simulation period to 2025. This is to reflect the significantly increased size of the worldwide renewable energy market as a whole compared to in the 1980s. The presence of international CO_2 reduction targets and increasing environmental pressures has greatly increased public and private investment in renewable energy devices across the world. This therefore makes for a larger, and higher-growth, international market for renewable energies[33].

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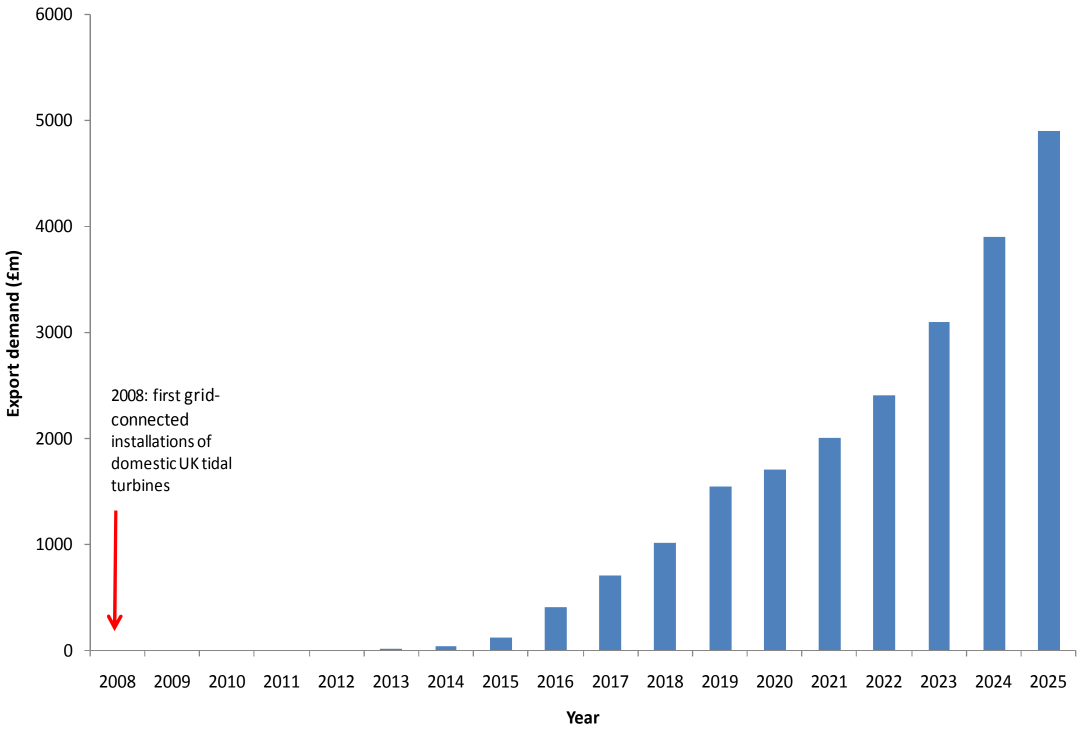
[32] There are alternatives to using the 2007 absolute value (of around £5bn) of Danish wind turbine exports as an indication of the potential export demand for UK tidal turbines. I also calculated the share of Danish tidal turbines as a percentage of GDP (and, similarly, as a percentage of total manufacturing, and as a percentage of total exports), and considered using the equivalent shares of UK GDP (and total manufacturing and total exports). However, since the UK economy is significantly larger than that of Denmark, this approach would translate to a much larger estimate for the potential UK exports for tidal turbines than the export demand considered in this chapter. In 2007, UK GDP was £1,618bn compared with £189.3bn for Denmark (similarly, UK exports were £433.6bn compared to £99.1 billion for Denmark, and UK manufacturing value added was £207.9bn, compared to £23.2bn for Denmark). Therefore, using Danish wind turbines as a percentage of GDP as a guide (equivalent to around 2.6% of Danish GDP) would translate to a projected export demand for UK tidal turbines of £42bn (using 2007 GDP data), compared to the £5bn estimate used here. Similarly, using Danish wind turbines as a percentage of total exports (around 5%) or total manufacturing (around 21.5%) as a guide would translate to UK export estimates of £21.6bn and £44.7bn. To put this in perspective, the US, which is the largest exporter of wind turbines in the world, and which clearly has a significantly greater productive capacity compared with the UK economy, exported around £13bn worth of wind turbines in 2008. It would also be useful to consider the size of the Danish export market as a percentage share of the world export market for wind turbines, however, there are no estimates for the latter. Therefore using the absolute level of Danish exports as a guide seems to be the most reasonable approach: I am assuming that the UK economy is able to achieve the same level of turbine exports as another small, open economy which is similarly rich in renewable resources and which has developed an export market on the basis of a strong domestic market for renewable energies. All data mentioned in this footnote have been obtained from the Eurostat statistics database (excluding the value of Danish tidal turbines and technologies – see Figure 6.5 for source): http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

[33] In the last fifteen years alone, worldwide investment in new renewable energy capacity has grown by 1,400%: from around $5bn in 1993 to around £70bn in 2008 (Renewable Energy Policy Network for the 21st Century, 2008).

Figure 6.7 Proposed export demand for UK tidal turbines and technologies 2008-2025 (£m)



Reflecting the 'establishment phase' of the UK turbine industry, the size of the total demand shock is necessarily small during the early years of the simulation time period. Over the period 2008-2015, I assume that the UK tidal turbine industry is supported by domestic demand only, with export demand shocks are introduced gradually over the thirteen year period from 2013 to 2025. This is based on the assumption that a domestic market for tidal turbines precedes that of an international market, and that early turbine exports are in response to international demand for prototype and commercial test devices. This is in line with the pattern of development of wind turbines in Denmark.

4.2.2 The sectoral distribution of the export shock

The aggregate estimate of UK tidal turbine exports is assumed to incorporate demands for tidal turbine capital goods (including component parts, electrical devices and so forth) as well as installation and operation and maintenance expenditures, and so the sectoral dispersion of the export demand stimulus is very similar to that of the domestic expenditures outlined in Table 6.3. Therefore the total international demand for UK-produced tidal turbines will be spread across the relevant UK sectors. However, there are some categories of expenditure that are clearly associated with domestic demand but not with export demand, including expenditure on UK seabed rents, for example. Therefore, some of the sectors which are affected by the domestic demand stimulus are not directly affected by the export demand shock. I exclude two of the categories of expenditure in Table 6.4 when calculating the share of the export stimulus across the sectors: spending on 'seabed rent' and the 'annual insurance costs', on the basis that basis that foreign tidal farm operators may be more likely to take insurance cover from local rather than UK firms. Therefore I allocate the total export demand stimulus across the UKENVI sectors according to the shares identified in Tables 6.3 and 6.4, though with the sectoral shares re-apportioned in order to take account of the two excluded sectors[34].

5. The UKENVI model

To model the economic impact of the establishment of a domestic and international market for UK tidal energy devices and technologies, I use a twenty-five sector CGE model which is parameterised on UK data. The model is described in detail in Appendix H. The use of CGE models for policy-related 'what-if' analysis is widespread (see Chapter 2), reflecting the usefulness of their multi-sectoral structure, combined with a fully specified supply-side. The framework is particularly useful given the exploratory nature of the analysis in this chapter. Furthermore, the twenty-five sectors of the UKENVI model provide a good level of disaggregation for the study. As such, the sub-sectors that would be affected by a domestic or international stimulus to the tidal energy sector can be directly targeted with the exogenous demand shock, and the consequential sectoral and aggregate economic impacts can be investigated.

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[34] The outcome of this re-organisation is that two UKENVI sectors which receive a share of the domestic stimulus do not receive a share of the export stimulus. These sectors are the 'public administration and education' sector (sector 16) and the 'communications, finance and business' sector (sector 18).

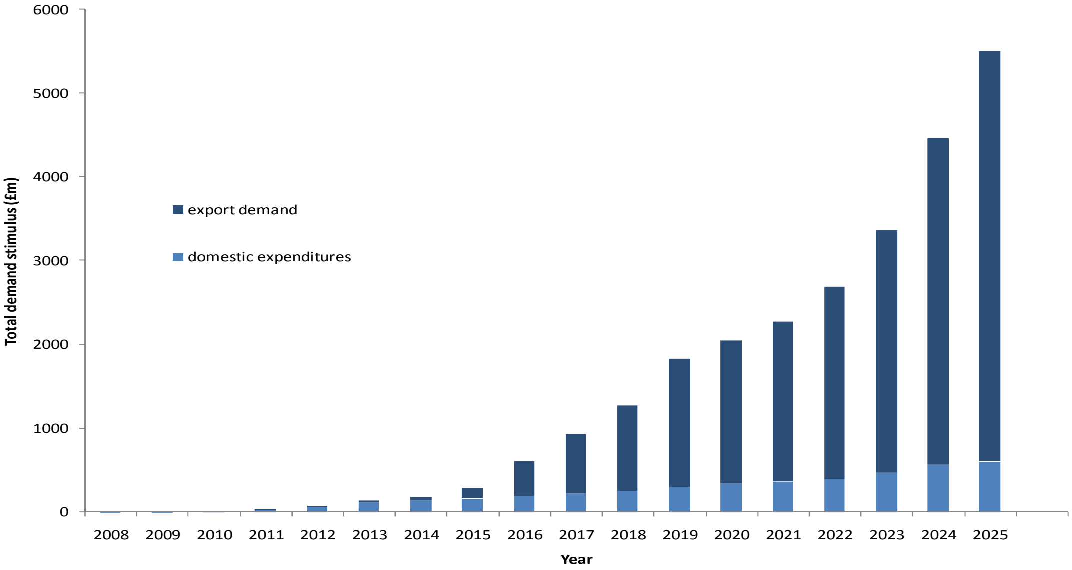
The sectoral disaggregation of the model also focuses on the UK energy sectors, including the disaggregation of electricity generation into renewable and non-renewable sources. Accordingly, the model has been used for a number of analyses that relate to the UK energy sector and UK energy policy. Allan et al. (2007b) use the UKENVI model to measure the impact of a 5% across the board improvement in the efficiency of energy use in all production sectors, and considers the extent of a 'rebound effect': the notion that an improvement in energy efficiency leads to a fall in the effective price of energy services, which thereby produces an economic response which at least partially offsets the expected beneficial impact of the energy efficiency gain. In Turner (2009), the author conducts systematic sensitivity analysis within the UKENVI framework in order to show the conditions under which the rebound effect may occur in response to increases in energy efficiency in the UK economy. These simulations vary the production function and trade parameters in order to affect the relative price sensitivity within the system. Allan et al. (2007c), considers the existence of a 'double dividend' effect with respect to energy policy: the hypothesis that substituting environmental taxes in place of distortionary taxes may produce a double dividend by deterring environmentally harmful activities but also by reducing the distortionary effects of the tax system. The UKENVI model is used to examine the implication of an increase in taxes paid on energy use alongside an offsetting reduction in the rate of social security contributions, which are the key elements of the UK government's Climate Change Levy package.

In terms of policy related to tidal energy, there have been a number of studies that look at the economic viability of new marine technologies (Department of Trade and Industry, 2007a), as well as studies that estimate the cost of renewable electricity that derives from renewable energy devices such as tidal turbines, but at the time of writing there are no studies that consider the economy-wide economic impact of the demand stimulus associated with developments in the tidal energy industry for the UK or, to my knowledge, for any other country.

6. Simulation strategy

The impact of increased domestic and export activity in the UK tidal energy industry is modelled via a series of exogenous demand shocks in the UKENVI model. The demand shocks are entered annually, for each period from 2008 to 2025. The size and time path of the shocks are determined by the total estimated demand for tidal turbines and technologies: the sum of the domestic expenditures (Figure 6.4) and the export demand (Figure 6.7). The aggregate demand stimulus is illustrated in Figure 6.8. The sectoral distribution of the shock is informed by the sector shares of the expenditures associated with domestic installations (Tables 6.3 and 6.4) and the adjusted sectoral disaggregation assumed for the export component of the demand shock (see Section 4.2.2). The resulting aggregate demand shocks are allocated to the appropriate UKENVI sectors.

Figure 6.8 The annual aggregate stimulus to the UK tidal sector 2008-2025



The annual expenditure stimuli are entered as exogenous demand shocks in each year during the period 2008-2025, and the UKENVI model is solved for a new, counterfactual equilibrium. The simulation results are compared to a counterfactual in which the long-run equilibrium position recreates itself, such that if the model is run forward without any disturbances it will replicate the base year values. Thus, no change in the composition or size of the UK economy is assumed. Nor is any exogenous disturbance imposed in the counterfactual simulation. Any changes relative to the base year can therefore be taken to be solely the result of the demand shock associated with the developments in the UK tidal sector that are described above.

The approach that I use implies that the developments in the tidal industry are costless for the public sector, and that they are financed entirely through commercial investments. In practice, there are likely to be additional impacts related to, for example, public sector investment which is financed through an increase in taxation. However, the use of a counterfactual which incorporates no other policy change is a necessary first step, since this isolates the effects which can be specifically attributed to the increase in demand for tidal turbine deployment. In Chapter 7 I discuss the constraints of this approach, and the potential for additional non-costless analyses which would complement the analysis.

6.1 Central case scenario

In the UKENVI model, there are several choices for the specification of the labour market, each imposing a single UK labour market characterised by perfect sectoral mobility. In the central case scenario, it is assumed that wages are determined by a bargaining process. As in the Bargaining configurations used in earlier chapters, real wages are determined via a conventional 'wage curve' operating at the national level. The real consumption wage is directly related to workers' bargaining power, with wages thus inversely related to the unemployment rate (Blanchflower and Oswald, 1994; Minford et al., 1994). The bargaining function is parameterised according to Layard et al. (1991):

$$w_t = \alpha - 0.068u + 0.40w_{t-1} \tag{6.1}$$

where:

w is the natural logarithm of the UK real consumption wage nominal wage rate

u is the natural logarithm of the unemployment rate
t is the time subscript
α is a parameter calibrated so as to replicate equilibrium in the base period[35].

The UK population is assumed to be fixed, and no balance of payments constraint is imposed.

6.2 Sensitivity analysis

Alternative specifications of the labour market are also available within the model structure, and varying these assumptions can have important implications for the model results. I examine the effects on the model results of incorporating three distinct views of how the national labour market operates. These include a Flow Migration scenario, whereby the Bargaining wage closure is combined with a migration function. In this configuration, net migration is positively related to the real wage differential and negatively related to the unemployment differential between the UK and the rest of the world. This description is based on the model of Harris and Todaro (1970), and has been econometrically estimated on UK data (Layard et al., 1991). Thus, over the simulation period, net migration flows in each period are used to update population stocks at the start of the following period. This process is similar to the endogenous updating of capital stocks, outlined in Appendix H. In practice, however, there are restrictions on international in-migration at the national level in the UK (in contrast to the migration flows between the regions of the UK), and migration policy may affect the size and trajectory of migration flows over time.

In the second alternative specification, I assume an Exogenous Labour Supply closure. This implies a wage-inelastic aggregate labour supply function. The real wage adjusts continuously in order to equate aggregate labour demand and a fixed labour supply. Aggregate employment is therefore effectively fixed. Evidently, this

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[35] Although the calibrated parameter plays no part in determining the sensitivity of the endogenous variables to exogenous disturbances, the initial equilibrium assumption of equilibrium is an important one.

is an improbable scenario, but nevertheless a fairly common labour market closure in national CGE models. In the final alternative specification, I impose a Real Wage Resistance closure. This involves imposing a fixed real consumption wage, with total employment changing so as to ensure labour market equilibrium. This has the implication that, in effect, the labour supply is infinitely elastic (over the relevant range) at the current real wage rate. This set-up could also be thought to capture an economy with perfect flow migration (McGregor et al., 1996b). These latter two specifications are clearly limiting cases, but they are considered primarily because they provide useful points of reference.

7. Simulation results

7.1 Central case scenario

Table 6.6 shows the aggregate impact of the domestic and export demand stimulus on the UK economy for the central case scenario. The results show that increased activity in the tidal turbine industry leads to an increase in GDP over the period (an increase of £457.1m by 2025 (Figure 6.9), or 0.06% of GDP). In line with the increase in demand for UK output, there is a rise in aggregate employment, consumption and consumer prices, though the percentage increases are fairly small. According to the Bargaining relationship, real wages also rise as the unemployment rate falls, though by a modest amount: the real take-home consumption wage is 0.15% higher than base by 2025. Figure 6.9 illustrates the GDP trajectory over the simulation period, and highlights that output rises gradually relative to base over the period 2008 to 2015, and thereafter increases to a greater extent, reflecting the introduction of significant export demands, and therefore a much greater aggregate demand stimulus, from around 2016 onwards.

Table 6.6 Central scenario summary results: change in key economic variables from base

	2010	2015	2020	2025
GDP (%)	0.000	0.002	0.014	0.056
Consumption (%)	0.003	0.019	0.126	0.345
Investment (%)	0.000	-0.007	-0.019	-0.016
Nominal before-Tax wage (%)	0.000	0.033	0.247	0.676
Real T-H consumption wage (%)	0.000	0.007	0.050	0.150
Consumer price index (%)	0.000	0.000	0.200	0.500
Total employment (%)	0.000	0.005	0.036	0.107
Unemployment rate (%)	0.000	-0.070	-0.453	-1.341
Exports (%)	0.003	0.055	0.373	1.002
Imports (%)	0.004	0.077	0.542	1.436
Total change in employment	8	1,413	13,075	28,449
GDP (£million)	1.118	18.454	114.078	457.061

Figure 6.9 GDP impact of the domestic and international demand stimulus (£m)

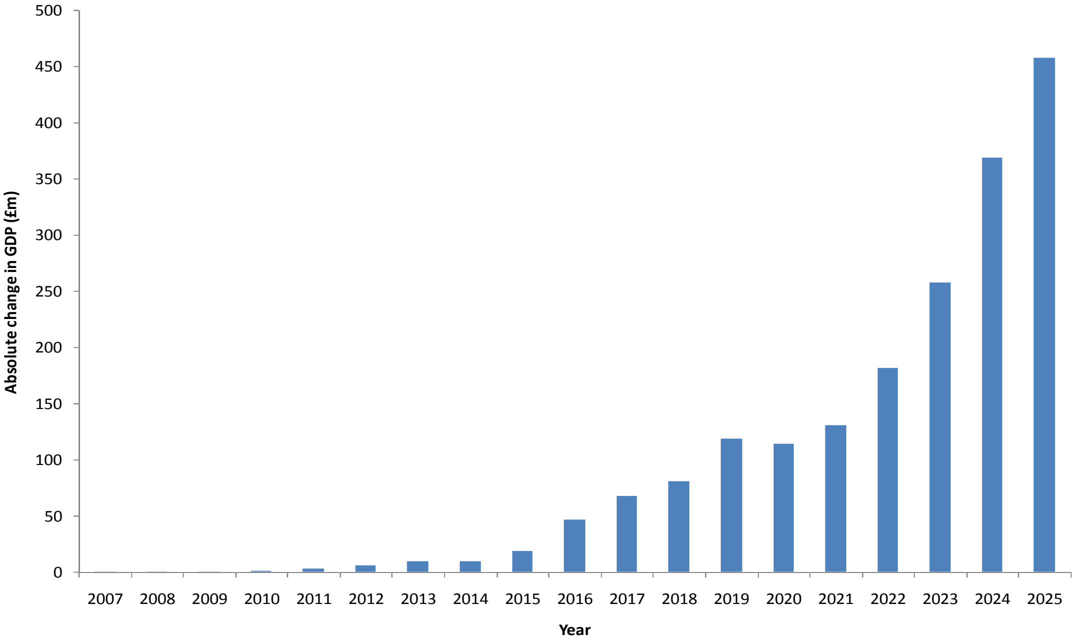
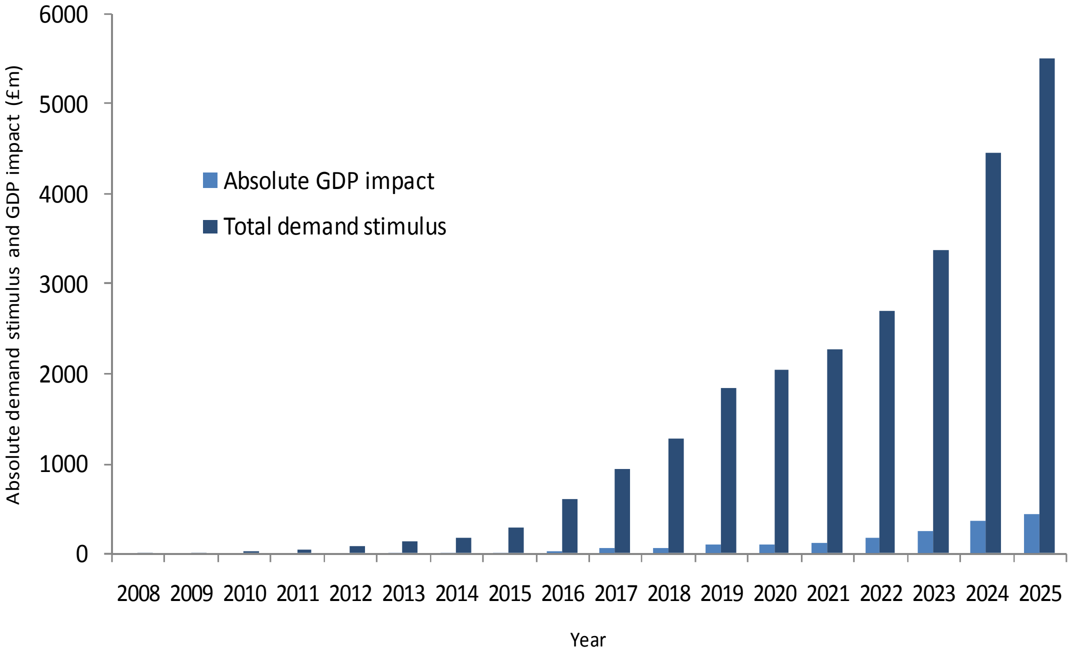


Figure 6.10 shows that the increase in GDP relative to base falls short of the annual aggregate domestic and export stimulus. This occurs for two key reasons. Firstly, although the entire demand stimulus is directed towards domestically-produced tidal turbine commodities, only a part of it contributes towards UK GDP. Some of the intermediate component parts required for turbine manufacture are imported, thus diverting a share of the expenditure out of the domestic economy. Therefore, the more developed are the backward linkages for the industry, the greater the share of the stimulus that remains in the UK, and the higher the aggregate impact of a demand shock to the tidal energy sector.

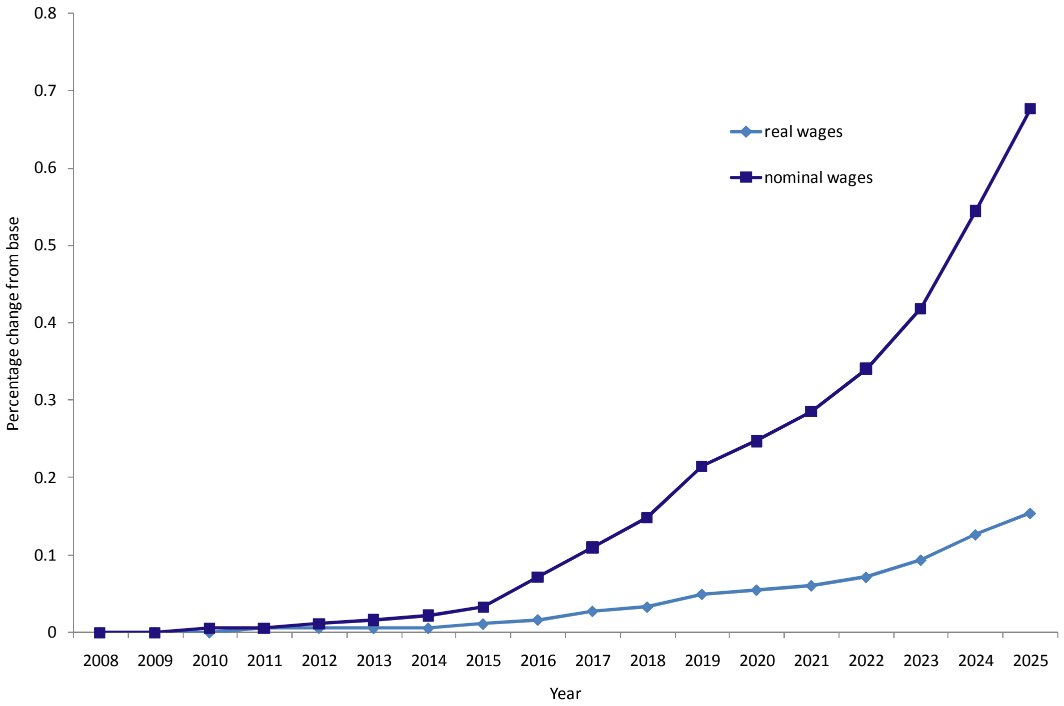
Figure 6.10 Absolute GDP impact and the total demand stimulus (£m)



Secondly, the increase in wages and the price of intermediate inputs for some sectors that accompanies the demand expansion crowds out activity in other sectors. This leads to a fall in competitiveness and a reduction in GDP in those other sectors, which contributes to a less-than-proportionate increase in aggregate activity. The real and nominal aggregate wage rate changes are shown in Figure 6.11. In those years where the larger export demand stimuli are introduced (i.e. from 2016 onwards), nominal wages rise sharply, which means that some exports are crowded out to facilitate the increase in activity in the tidal industry sector.

The nature of the crowding out effects means that the impact of the demand stimulus on aggregate investment is contrary to expectations: investment falls relative to base over the period to 2025, though by a modest reduction of 0.02% by 2025 (Table 6.6). Although capital stocks increase in most of the stimulated sectors (with the exception of the 'communications, finance and business' and 'public administration and education' sectors, which are affected only by the smaller domestic demand component of the shock), capital stocks fall in most of the non-stimulated sectors, to the extent that the net effect on investment is negative. The sectoral concentration of the demand stimulus means that the detrimental effects on the non-stimulated sectors – which are discussed in more detail below – are significant.

Figure 6.11 Percentage change in real and nominal wages



The overall increase in GDP is primarily driven by an increase in output and employment in those sectors that benefit from expenditures associated with the production of capital goods for the tidal sector (such as component parts, electrical devices and so forth), rather than those sectors affected by the smaller operations and maintenance component of the expenditure stimulus. The sectors in which the majority of the expenditures are made include the 'other machinery', 'electrical and electronics' and 'construction' sectors (UKENVI sectors 10, 11 and 14, respectively). Increased returns on capital lead to a rise in economic activity and employment in these sectors, and the extent of these effects are sufficient to increase aggregate employment and reduce aggregate unemployment. However, for two of the sectors which receive a direct demand stimulus, there is a fall in output: the 'communications, finance and business' and the 'public administration and education' sectors (UKENVI sectors 16 and 18, respectively). It is these sectors which are associated with operation and maintenance expenditures only. This occurs because I assume that these sectors receive a direct demand shock from only the domestic, and not the larger export, element of the total demand shock. Figure 6.12 illustrates the aggregate employment effect, whilst Figure 6.13 illustrates the changes in employment across the sectors in the final simulation period, year 2025.

Figure 6.12 Aggregate employment impact of the domestic and international demand stimulus

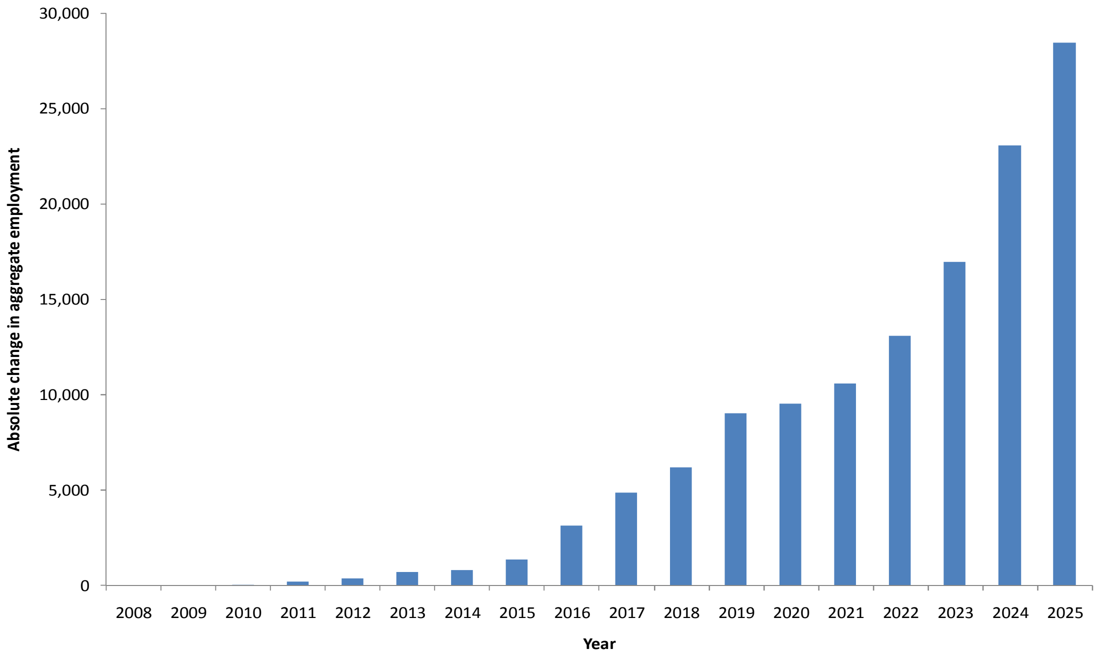
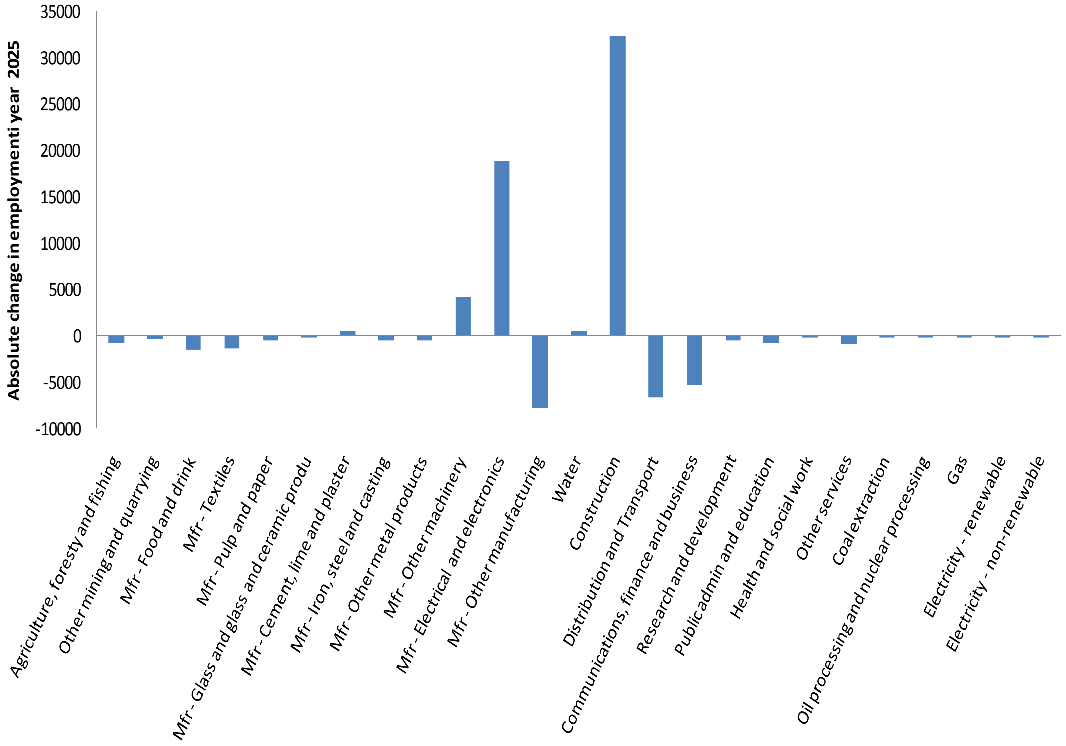


Figure 6.13 Absolute change in sectoral unemployment in year 2025



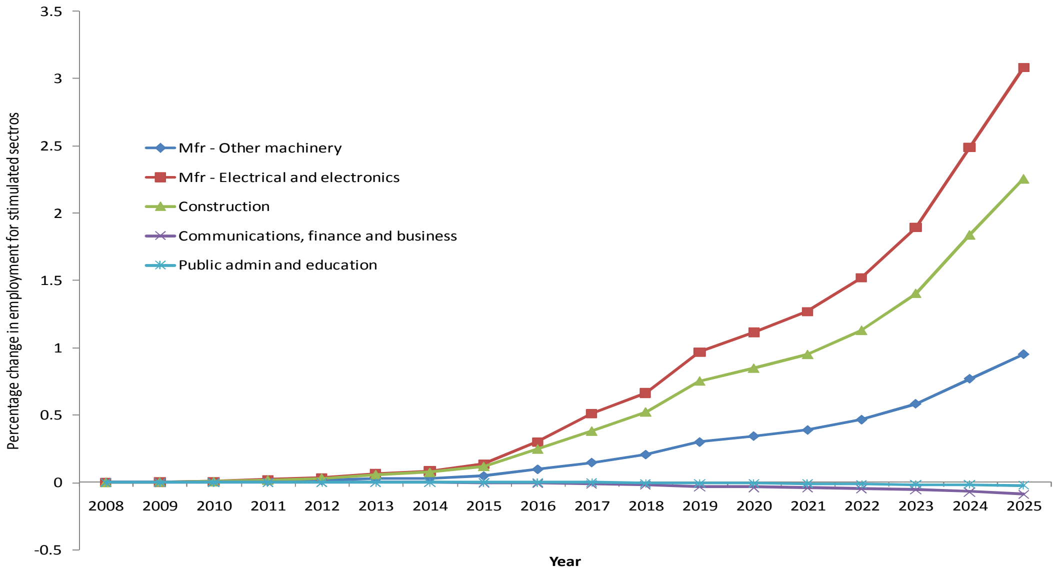
The aggregate effect on employment is qualitatively similar to the effect on GDP: a similar gradual increase in employment is observed until around 2015, after which time there are larger increases in employment relative to base, corresponding to the larger size of the export stimuli which are imposed after this period. Within this aggregate employment result, however, there are clear differences in the sectoral employment impacts. These differences reflect, amongst other factors, the degree to which each of the sectors experience a direct demand stimulus, and the extent of crowding out across the sectors. In general, employment in those sectors that are directly influenced by the increase in demand is positively affected. The sectors which are affected by both the domestic and the larger export component of the shock experience an increase in activity and employment. This, however, crowds out activity from most of the other sectors which are not directly affected by the demand stimulus. Moreover, as for the GDP results, even two of those sectors which are directly affected by the increase in domestic expenditures - though crucially not by the export stimulus - experience a fall in employment as activity is directed away from these sectors (the ‘communications, finance and business’ and ‘public administration’ sectors, as before). Table 6.7 details the absolute change in employment across the UKENVI sectors.

Table 6.7 Sectoral employment effects

UKENVI Sector		**Initial sectoral employment**	**Absolute change in employment (FTE jobs)**			
			2010	**2015**	**2020**	**2025**
1	Agriculture, forestry and fishing	277,015	78	-40	-312	-809
2	Other mining and quarrying	77,048	-1	-15	-124	-341
3	Food and drink	596,646	0	-68	-553	-1,431
4	Textiles	314,132	-2	-68	-525	-1,401
5	Pulp, paper and board	120,954	-3	-26	-197	-514
6	Glass and glass products	99,732	-1	-6	-23	-33
7	Cement, lime plaster and concrete	71,626	0	25	215	601
8	Iron, steel first processing	144,933	1	-28	-188	-474
9	Other metal products	486,736	-2	-60	-279	-537
10	Other machinery	447,245	-4	214	1,537	4,261
11	Electrical and electronics	613,263	12	848	6,831	18,881
12	Other manufacturing	1,871,719	41	-408	-3,025	-7,874
13	Water	41,890	-20	5	20	60
14	Construction	1,433,158	1	1,705	12,155	32,305
15	Distribution and transport	6,732,224	87	-363	-2,822	-6,581
16	Communications, finance, business	5,951,798	-15	-207	-2,221	-5,315
17	Research and development	117,815	-11	-21	-159	-411
18	Public admin and education	3,480,141	-1	-23	-284	-761
19	Health and social work	2,322,687	-1	-2	-45	-172
20	Other services	1,224,088	0	-41	-358	-840
21	Coal (Extraction)	16,754	-1	-2	-10	-24
22	Oil processing and nuclear refining	33,894	0	-6	-42	-108
23	Gas	32,900	-1	0	-2	-2
24	Electricity - Renewable	3,032	0	0	-1	-1
25	Electricity - Non-renewable	90,571	0	-2	-15	-32
Total		**26,602,001**	**157**	**1,411**	**9,573**	**28,447**

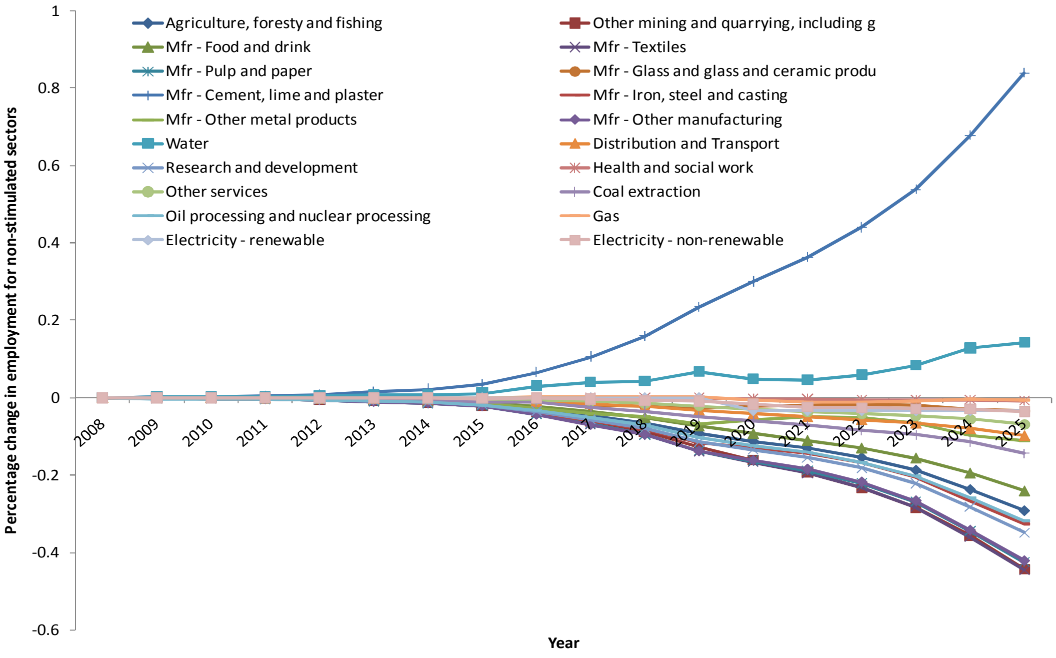
Figures 6.14 and 6.15 show the evolution of the change in employment for the sectors that receive a share of the demand stimulus, and those which are not directly stimulated, respectively, and clearly show the crowding out effects of the shock. For the sectors which are stimulated by both domestic and international demand, commodity prices increase, as do commodity outputs, the return on capital, and capital stock. However, the results are quite different for the two stimulated sectors that are only affected by the domestic component of the shock. In the ‘communications, finance and business’ sector, there is an increase in commodity prices, in line with the increase in aggregate prices, and this is accompanied by a fall in sectoral output and a fall in capital stock. The fall in activity in this sector is associated with a slight percentage reduction in employment by the year 2025 (Figure 6.14). The ‘public administration and education’ sector follows a similar path, although there is a small increase in sectoral output in the early years following the demand stimulus, after which sectoral output falls, and this too is accompanied by a percentage reduction in sectoral employment by the end of the simulation period, albeit this is a minor effect. Crucially, each of these sectors is directly affected only by a small proportion of the overall stimulus by 2025, and this is insufficient to compensate for the negative impact of rising wages.

Figure 6.14 Percentage change in employment for stimulated sectors



For the non-stimulated sectors, although there are positive indirect and induced effects that derive from the expansion in activity in the sectors affected by the total demand shock, the crowding out effects are sufficient to result in an overall reduction in activity in most of these sectors. In general, as commodity prices rise in these sectors, capital stocks and output falls, and this is associated with a fall in employment across the sectors (Figure 6.15). The fall in capital stocks in these sectors is significant enough to lead to a reduction in aggregate investment in the economy relative to base during the simulation period (see Table 6.6), despite the increase in capital stocks in the stimulated sectors. However, there are exceptions to this pattern of falling sectoral outputs, employment and capital stocks for two non-stimulated sectors: the 'other manufacturing – cement, lime and plaster' and the 'water' sectors. Following the demand shock, in the stimulated sectors there is an increase in demand for intermediate components which are intrinsic to tidal turbine installations, such as cement. For the 'other manufacturing – cement, lime and plaster' and 'water' sectors, this indirect demand stimulus is sufficient to outweigh the negative effects of higher-priced inputs, so as to generate positive long-run effects on sectoral output, employment and capital stocks. This reflects the close intersectoral linkages between these two sectors and the stimulated sectors.

Figure 6.15 Percentage change in employment for non-stimulated sectors



7.2 Sensitivity analysis

In the central case scenario, I find that the effect of the demand stimulus on aggregate activity is governed strongly by the extent of crowding out that occurs via wage and price increases. The model assumptions regarding labour market behaviour can have important implications for the macroeconomic effects of any exogenous economic stimuli, and in this section I consider a range of alternative views about the configuration of the national labour market, including different wage-determination assumptions, and their impact on the results. A key objective in doing so is to identify which factors influence the degree of crowding out in the economy.

Table 6.8 summarises the key results for the Flow Migration scenario, which is identical to the Bargaining configuration but for the allowance for in-migration to the UK.

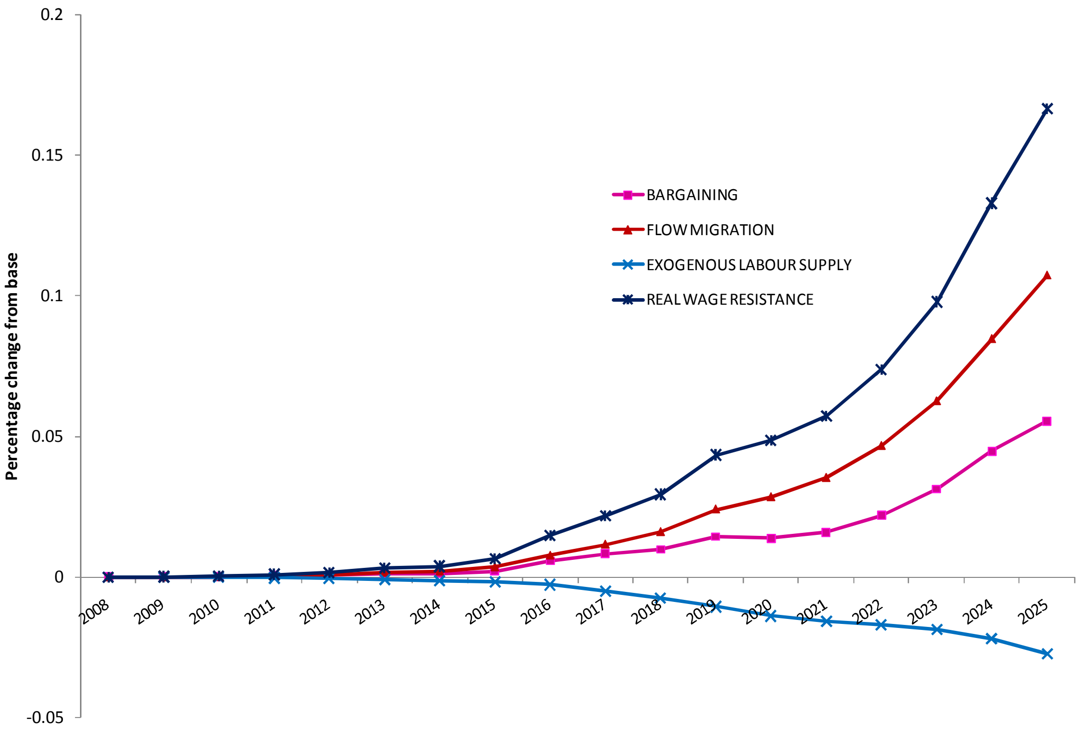
Table 6.8 Flow Migration summary results: change in key economic variables from base

	2010	2015	2020	2025
GDP (%)	0.001	0.004	0.029	0.107
Consumption (%)	0.003	0.020	0.141	0.396
Investment (%)	0.000	-0.005	0.004	0.061
Nominal before-Tax wage (%)	0.000	0.033	0.220	0.588
Real T-H consumption wage (%)	0.000	0.007	0.029	0.086
Consumer price index (%)	0.000	0.000	0.200	0.500
Total employment (%)	0.000	0.007	0.056	0.174
Unemployment rate (%)	0.000	-0.052	-0.244	-0.749
Exports (%)	0.003	0.056	0.385	1.047
Imports (%)	0.004	0.078	0.551	1.460
Total change in employment	9	1,907	21,821	46,395
GDP (£million)	1.377	29.220	234.592	883.020
Population	57	2,020	21,740	67,528

In line with the results of the Bargaining scenario, there is an increase in GDP and employment following the demand shock in the Flow Migration configuration. However, in this scenario, there is a relatively stronger boost to aggregate output compared with the central Bargaining case: GDP increases by 0.11% in the Flow Migration scenario by 2025, compared with an increase of 0.06% in the Bargaining set-up (Table 6.6). The effects of the shock feed through in the same way as in the central Bargaining configuration: there is a rise in output and employment in those sectors which benefit from the increase in expenditures associated with both the domestic and the export component of the shock, and also in other sectors via indirect and induced effects. As activity expands, the responsiveness of the real wage works to increase aggregate prices and reduce competitiveness in the economy, as in the Bargaining scenario, and this offsets the positive demand stimulus to some extent. Nominal wages rise, such that some exports are crowded out to accommodate the increase in activity in the tidal turbine sectors, though the overall impact on exports is still positive (Table 6.8). For the non-stimulated sectors, in general, these crowding out effects are sufficient to lead to an overall decrease in output and employment. In this scenario, however, the introduction of migration lessens the crowding out effect. The relative fall in unemployment and rise in real wages leads to in-migration, and this increase in the labour supply mitigates the increase in real wages: by period 2025, real wages rise by 0.09% in this scenario in 2025, compared with an increase of 0.15% under the Bargaining case for the same period. Nominal wages also rise by less: 0.59% in the Flow Migration scenario compared to 0.68% in the Bargaining scenario. Consequently, the negative competitiveness effects are lessened under this scenario, and the crowding out effects are moderated.

Furthermore, the impact of the crowding out effects on investment is not so detrimental, in contrast to the Bargaining scenario. In general, capital stocks do fall in the non-stimulated sectors over the period to 2025 (and also in the two sectors that are stimulated only by the smaller, domestic, component of the demand shock), but this is not sufficient to lead to a reduction in net investment. As a result, overall investment rises by 0.02% in this scenario in 2025, compared with a fall of 0.02% in the Bargaining configuration for the same period. These effects lead to a higher GDP trajectory for this labour market set-up compared with the Bargaining scenario (Figure 6.16), and this is reflected in a larger rise in employment (an increase of 46,395, compared with 28,449 in the central case in 2025).

Figure 6.16 Percentage change in UK GDP



The other two labour market specifications that are considered – the Exogenous Labour Supply and the Real Wage Resistance closures – together represent limiting cases which, in effect, reflect labour supply elasticities of zero and infinity with respect to the real consumption wage. In the Exogenous Labour Supply scenario, where aggregate employment is effectively fixed, there is, as expected, a significant increase in real wages in response to the demand shock. By period 2025, real wages are 0.27% higher than base, compared to an increase of 0.15% and 0.09% in the Bargaining and Flow Migration configurations, respectively. This leads to significant crowding out effects. The impact of the demand shock on the stimulated sectors is still generally positive (with the exception of the two sectors only affected by the smaller domestic element of the stimulus), with output and employment increasing in these sectors for the duration of the simulation period. However, the magnitude of the crowding out effects in the non-stimulated sectors is sufficient to lead to a reduction in aggregate output over the simulation period to 2025. In this year, GDP falls by 0.03% relative to base (compared to a rise of 0.06% in the central

Bargaining case and 0.11% in the Flow Migration scenario), and this scenario results in the lowest GDP trajectory out of all the scenarios considered (Figure 6.16).

Table 6.9 Exogenous Labour Supply summary results: change in key economic variables from base

	2010	2015	2020	2025
GDP (%)	0.000	-0.002	-0.014	-0.027
Consumption (%)	0.003	0.017	0.110	0.298
Investment (%)	0.000	-0.013	-0.058	-0.130
Nominal before-Tax wage (%)	0.000	0.044	0.302	0.836
Real T-H consumption wage (%)	0.000	0.014	0.086	0.265
Consumer price index (%)	0.000	0.000	0.200	0.600
Total employment (%)	0.000	0.000	0.000	0.000
Unemployment rate (%)	0.000	0.000	0.000	0.000
Exports (%)	0.003	0.050	0.338	0.897
Imports (%)	0.004	0.077	0.543	1.439
Total change in employment	0	0	0	0
GDP (£million)	-0.511	-12.894	-112.740	-222.763

In contrast, the Real Wage Resistance closure gives rise to the largest increase in aggregate activity across all the labour market configurations. In this set-up, the labour supply is effectively infinitely elastic with respect to the prevailing real wage rates. As expected, the extent of crowding out is minimal in this scenario compared to the other set-ups, since there are no labour supply constraints to drive up the real wage rate, and the increase in the nominal wage rate is lower than in any of the other scenarios (nominal wages rise by 0.46% by 2025, compared with an increase of 0.68% in the central scenario). Consequently, exports rise by most in this scenario (by 1.14% in 2025, compared with an increase of 1.00% in the central case, and an increase of 1.05% in the Flow Migration case, where the crowding out effects are mitigated by the effects of in-migration. In the Real Wage Resistance scenario there are still some negative competitiveness effects feeding through as a result of the demand shock: employment and output in most cases fall across the non-stimulated sectors, and also in the sectors affected only by the domestic constituent of the demand shock. These effects are small, however, compared with the other configurations. Similarly, although there is generally a fall in capital stocks in the non-stimulated sectors (with the exception of the 'cement, lime and plaster' and the 'water' sectors), the effect on net investment is still positive. Investment increases by 0.14% relative to base in this scenario, compared to a decrease of 0.02% in the central case. Combined, these factors contribute to an increase in GDP of 0.17% relative to base, compared with an increase of 0.06% in the Bargaining configuration.

Table 6.10 Real Wage Resistance summary results: change in key economic variables from base

	2010	**2015**	**2020**	**2025**
GDP (%)	0.001	0.007	0.049	0.166
Consumption (%)	0.003	0.021	0.146	0.409
Investment (%)	0.000	0.000	0.030	0.138
Nominal before-Tax wage (%)	0.000	0.027	0.176	0.456
Real T-H consumption wage (%)	0.000	0.000	0.000	0.000
Consumer price index (%)	0.000	0.000	0.200	0.500
Total employment (%)	0.000	0.011	0.082	0.251
Unemployment rate (%)	-0.017	-0.157	-1.045	-3.151
Exports (%)	0.003	0.061	0.417	1.142
Imports (%)	0.004	0.077	0.542	1.433
Total change in employment	16	3,038	30,883	66,827
GDP (£million)	2.797	54.344	399.020	1368.797

8. Policy issues and further discussion

In addition to the assumptions made regarding the resource capacity, turbine cost estimates and export demand and so forth, this analysis also relies on a number of additional, implicit, assumptions. These include, for example, the availability of a skilled labour supply, sufficient capacity and connectivity of the UK National Grid, and a competitive and viable price for electricity generated by tidal energy technologies. In practice, however, there are a number of systemic barriers to growth for the tidal energy sector, which could constrain the size of the economic impact associated with development of the sector. For the domestic industry, past surveys of investor attitudes signalled that emerging technologies such as tidal stream have struggled to attract investment from key commercial organisations due to their being considered as high-risk investments (House of Lords Select Committee on Economic Affairs 2004, 2008) and as a result of the perceived insufficient and inconsistent energy sector policy of the UK government relative to other countries (House of Commons Select Committee on Science and Technology, 2007). This deficiency of investment funds is an effect that is likely to have been further exacerbated by the recent financial crisis. Planning restrictions are also of significant concern (House Of Lords Select Committee on Economic Affairs, 2008), as are the capacity constraints of the UK National Grid at areas where tidal electricity generation would be most concentrated (British Wind Energy Association, 2006).

With regards to the international market for UK tidal commodities, the implicit assumption embodied in this analysis is that the domestic industry is able to replicate at least some aspects of the Danish model of the wind turbine industry, in order to achieve a competitive advantage in the production of tidal turbines and a significant share of worldwide revenues. This assumption, in particular, is non-trivial. The successful development of the Danish wind turbine industry since 1980 rests on a wide range of factors, encompassing progressive energy policy objectives, compatible political and social principles, as well as industry compliance within the Danish economy. The policy mechanisms in place included consistent price signals: high energy taxation on fossil fuels; wind investment subsidies that were adjusted downwards as the wind industry grew; and long-term feed-in tariffs which provided investors with the certainty required to expend large amounts of investment capital. These feed-in tariffs were set at fairly high levels relative to market rates for non-renewable energy sources, making it highly profitable for both individual households and private companies to invest in wind turbines (Morthorst, 1999, 2000). In addition, there was open and guaranteed access to the Danish grid: transmission operators were obliged to connect wind power generators, and to expand the grid where necessary. Crucially, there were also long term financial guarantees in place for large wind projects, which encouraged local manufacturing, and helped to establish a strong domestic market for wind power.

The social ethos of renewable energy provision also played a role in the growth of the industry. In Denmark, wind turbines are often incorporated into urban, rather than only remote, landscapes, including in public parks and business areas. Consequently, the production of wind power is visible and widely distributed (Sovacool et al., 2009). This is in contrast to other countries, including the UK, where electricity production and consumption tends to be separated and electricity production plants are often out of sight. This approach has helped to generate strong social acceptance of and support for the renewables sector in Denmark, to the extent that recent renewable energy objectives announced by the Danish government have been widely criticised by voters as being insufficiently progressive (Sovacool et al., 2009). Meyer (2007) argues that such broad public support for the wind energy industry in Denmark is related to a number of factors, including systematic government support, co-operative private ownership of wind turbines, and the financial incentives provided by favourable feed-in tariffs for Danish citizens.

The Danish approach to research and development has also been attributed to helping the industry to succeed in its early years. Manufacturers followed an incremental learning-by-doing approach, in contrast to German and US manufacturers, who focused on rapid, large-scale commercial deployments (Heymann, 1998). Danish makers were therefore more flexible and able to adapt more easily to significant technological improvements without forfeiting heavy investments in earlier designs.

The advantages of adapting to these technological improvements, combined with economies of scale from the existence of a strong and stable domestic market, meant that the wind turbine industry was able to compete effectively in world markets (Lewis and Wiser, 2007).

In the UK, there are clearly stated objectives for the reduction of greenhouse gases and the increase in renewable energy targets, with the Renewables Obligation policy being the main mechanism for achieving these targets. However, in comparison to the Danish model of the renewable energy industry, UK energy policies are so far less interventionist and social and industrial attitudes less progressive. The comprehensive nature of the Danish policies and circumstances suggest that a number of additional measures may be required for the UK tidal industry to follow a similar development path to that assumed in this analysis. However, this raises a number of issues regarding the nature and extent of appropriate government support, and consensus is still to be reached regarding the exact form any additional policy measures should take, or whether they should be pursued at all.

Moreover, the requirement for a consistent, comprehensive approach to renewable energy policy highlights some points of concern regarding the multi-level governance of the UK economy and the devolution of some limited aspects of Scottish energy policy to the Scottish Parliament. The devolution arrangements of the 1998 Scotland Act involve the division of powers between UK and Scottish governments for a range of policy areas. Energy policy, and the key policy instruments that can influence the energy industry (i.e. taxation and regulation) remain reserved powers for the UK government. Within energy policy, the Scottish government has responsibility only for the promotion of renewable energy and energy efficiency, and the Scottish Parliament currently has no power to vary taxes, other than the ability to vary the standard rate of income tax by up to 3p in each pound. This arrangement suggests that there is relatively little scope for significant policy-making with regards to renewable energy decisions in Scotland. In practice, however, the Scottish government and Parliament have interpreted the powers widely enough to develop a distinctive energy policy influence. This includes the setting of separate targets for renewable energy generation and pollution emissions that are more progressive than the UK government's objectives for energy policy. This is embodied in the Scottish government's target to reduce greenhouse gas emissions by 42% relative to 1990 levels by 2020, compared to the UK's target of 34%[36]. Similarly, the Scottish government is committed to sourcing 20% of its energy supply from renewable sources by 2020, compared to an equivalent pledge of 15% by the UK government[37].

These different policy aims have directly translated to differences in decision-making, and highlight the potential difficulties for policy co-ordination amongst the Scottish and UK governments, with regards to tidal and other renewable energy initiatives. Recent amendments to the Renewables Obligation highlighted this tension in policy objectives: in a statutory review of the original Renewables Obligation, the UK government stated that the current flat-rate method of awarding Renewables Obligation Certificates (ROCs)[38] was working well (Department of Trade and Industry, 2005), whilst around the same time the Scottish Executive announced its intention to award supplementary ROCs to marine energy technologies (Scottish Executive, 2005). More recently, both the UK and Scottish governments have announced that they are in favour of banding ROCs to this effect, in order to encourage effective industry development for newer renewable energies such as marine technologies. However, the Scottish government intends to introduce more generous support for marine energy projects than the UK government. Whilst Scottish ministers will offer five ROCs for every megawatt-hour of power generated by wave energy projects and three for tidal projects, the UK government will offer

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[36] Scottish Parliament (2009) and Committee on Climate Change (2008). The Scottish and UK governments have set equivalent targets for the reduction of greenhouse gas emissions by 2050, of 80% compared to 1990 levels.

[37] The Scottish Government (2008a) and the Prime Minister's Speech on creating a low carbon economy (June 2008) retrieved from http://www.number10.gov.uk/Page16141

[38] ROCs are awarded to eligible electricity suppliers for the provision of renewable electricity to UK customers.

only two ROCs for both wave and tidal projects[39]. A similarly divergent view on nuclear power exists between the Scottish and UK governments. The UK government has implied that nuclear power stations have an important role to play in the UK's future energy mix (Department of Trade and Industry, 2007b). Indeed, recent announcements have suggested that there are prospects for a significantly expanded role for nuclear power generation in the UK[40], in line with efforts to decarbonise the UK electricity sector. In contrast, the Scottish government has announced its intention to phase out nuclear power provision (Scottish Government, 2007b). Whilst in principle nuclear energy is a reserved matter, the 1989 Electricity Act necessitates Scottish Ministers' consent for any building applications relating to nuclear power stations[41], and the Scottish government has been clear that it would be reluctant to approve any such applications, despite warnings from the UK government that this could 'undermine its energy policy' for the UK[42].

This particular issue perhaps implies that not only is there a variation in policy targets between the Scottish and UK governments, but also a divergence in the underlying objectives of energy policy. Whilst the UK government apparently sees continued nuclear energy provision as a means to help achieve environmental targets linked to reducing carbon emissions, so too does the Scottish government perceive its 'no nuclear' policy as contributing to its environmental objectives, albeit these are related to the longer term environmental concerns over the storage of nuclear waste, rather than to emissions targets (Scottish Government, 2008a). This fundamental

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[39] House of Commons Hansard Debates, April 2009, retrieved from http://www.publications.parliament.uk/pa/cm200809/cmhansrd/cm090428/halltext/90428h0002.htm. The amended bands introduced by the UK government came in to force on April 1st, 2009. Previously, the Scottish government also introduced an amendment to the original Renewables Obligation (Scotland) statutory provision, which was also intended to offer support to wave and tidal developers. This amendment is the Marine Supply Obligation (MSO), which obliges suppliers, for whom the Renewables Obligation is relevant, to meet a share of that requirement via wave or tidal energy generation in Scottish waters, or by accepting a higher buy-out cost. The wave and tidal requirements were set at zero for the period 2008/09, and were intended to be set annually, in line with developments in the industry. The intention is that the banded ROCs could potentially replace the MSO as a way of assisting the growth of the marine sector in Scotland (Scottish Parliament, 2008).

[40] 'The Future of Utilities', speech by the Secretary of State for Business, Enterprise and Regulatory Reform by the Rt. Hon. John Hutton MP, to the Adam Smith Institute, March 2008. Available at: http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk//pressroom/Speeches/page45211.html.

[41] According to Section 36 of the Electricity Act 1989.

[42] In its evidence submission to the Calman Commission on the future of devolution in Scotland (Commission on Scottish Devolution, 2009).

difference in energy policy aspirations also extends beyond the issue of nuclear power generation. As a key aim of its energy policy, the Scottish government has emphasised the potential for the energy sector, particularly renewable energies such as marine power, to provide a stimulus to economic growth (Scottish Government, 2007b, 2008a), whereas there does not appear to be explicit weight attached to the economic development contributions of the energy sector in the UK's energy policy objectives.

These distinct policy priorities likely reflect, in part, the uneven distribution of renewable electricity-generating resources across Scotland and the UK. Scotland is a net exporter of electricity production, while the reverse is true for the RUK. Similarly, for renewable energy resources, a disproportionately large share of the UK's renewable capacity is located in Scotland (Department for Trade and Industry, 2006a). This is true for the tidal energy resource of the UK, with Scotland's share of the total resource ranging from an estimate of around 38% up to 68%[43]. It is therefore likely that a disproportionately large share of the effects highlighted in this analysis could be concentrated in Scotland, relative to its contribution to UK GDP, and this would be especially true if clusters of marine energy sector activity congregate in areas near to the resource, and the existing established research and development clusters in Scotland. Thus the Scottish government's more ambitions energy targets possibly reflect the expectation that emissions reductions and increases in renewable energy uptake can be achieved at a lower cost in Scotland, and that the contributions to aggregate activity could be higher than in the RUK.

This study highlights the overall UK impact of developments in the tidal turbine sector, but the unequal distribution of the resource across the UK, and the differing policy objectives outlined above, therefore suggest that an interregional analysis of the issue would be beneficial. This is especially significant given the analysis in Chapters 3 and 4 of this thesis, where I demonstrate that divergent regional responses may be possible for economic shocks that generate positive national effects. In Chapter 3, for example, I show that, in the presence of bargained real wages and

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[43] Sustainable Development Commission (2007) and ABPmer (2007).

interregional migration, an export shock which is regionally and sectorally concentrated in the Scottish manufacturing sector leads to an increase in activity for the Scottish economy and the UK as a whole, but a fall in GDP in the RUK. This negative spillover effect for the non-target region arises due to supply-side constraints, as the labour supply migrates towards the relatively higher-wage and lower-unemployment region of Scotland. These findings suggest that an export shock for the tidal industry, which is also likely to be concentrated in Scottish production sectors, could potentially have negative other-region implications. Whilst the results of this chapter indicate an increase in activity for the UK following the export shock, a more detailed analysis could reveal that opposing interregional dynamics underlie the aggregate impacts.

Such potential interregional spillover effects, and the associated concerns for policy co-ordination, are also relevant in the context of the wider discussion regarding energy policy-making and the appropriateness of the current allocation of spatial levers for energy policy. The Commission on Scottish Devolution (2009) recognises that there are problems and/or pressure to change some aspects of the division of responsibilities between the Scottish and UK government, including within energy policy. Additionally, one recommendation of the report is that some ‘green taxes’ - important instruments in relation to environmental issues - should be devolved to the Scottish Parliament[44]. However, given the existence of wide-spread interregional trade between Scotland and the RUK, there are likely to be significant other-region implications which result from the use of such levers at either the Scottish or UK level. Therefore, a spatially and sectorally detailed analysis of the impacts of regional energy policies would be an informative contribution to the discussion about the appropriate allocation of policy levers, though this cannot be attempted in the absence of a suitably-aggregated dataset.

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[44] This specifically relates to taxes on: air passenger duty; the extraction of aggregates (i.e. crushed rock, sand and gravel) from the environment; and the disposal of waste to landfill, rather than taxes levied on energy or carbon-intensive inputs or outputs.

9. Conclusion

The UK's portfolio of electricity generation techniques will undergo considerable changes over the coming years, with increased emphasis on local, renewable energy resources such as on and off-shore wind and wave and tidal technologies. The UK has considerable renewable energy resources, and in this chapter I attempt to quantify the economic impact of the development of the UK tidal energy sector. Substantial expenditures in a range of UK sectors would be associated with the production, installation and operation of tidal energy devices and, moreover, sizeable worldwide energy resources imply that there could be vast potential export revenues for the industry.

The results of the analysis suggest that the demand stimulus could potentially deliver a significant economic benefit to the UK. There are likely to be crowding out effects associated with the shock, and the impact would vary across the UK sectors. The sensitivity analysis indicates that the characteristics of the national labour market, including wage-setting and migration behaviour[45], are important determinants of the crowding out effects.

Furthermore, the size and evolution of the aggregate economic impacts are contingent upon various explicit assumptions - such as the size of the UK tidal power resource, the degree of local sourcing and the size of the export market - as well as implicit assumptions regarding the existence of sufficient government support for the industry and a viable cost of electricity production for tidal power generation devices. In practice, the actual extent of domestic and international tidal technology deployment to 2025 will depend on a complex mix of technological, economic and political factors. There is therefore considerable uncertainty surrounding the model results. Any changes in the assumptions will likely affect the size and trajectory of the economic impacts. For example, if the resource estimates of ABPmer (2007) or Salter (2005, 2007), which are far greater than the estimate used in this analysis,

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[45] In practice, there are restrictions on migration flows into the UK (in contrast to the interregional migration flows considered in Chapters 3 and 4). Current UK migration policy may therefore influence the actual magnitude and dynamics of inmigration over time.

prove to be accurate then there could be a much larger domestic market for tidal turbines, and a correspondingly greater stimulus to UK economic activity. As such, the results of this analysis should be interpreted as an ex ante analysis of a relevant policy concern of the UK and Scottish governments, rather than a specific prediction about the likely impact of changes in the UK's renewable energy supply. There is therefore much scope for additional sensitivity analysis around the key model assumptions, such as the size of the UK resource, the potential for local sourcing of tidal turbine components, and the timepath for installation of the devices. Furthermore, as more information and technical research on resource capacity and so forth becomes available, future research could incorporate more accurate assumptions and inferences based on implied levels and types of government support, evidence of backward linkages forming and export demand, for example. In particular, in the presence of more anecdotal evidence to inform a realistic tidal turbine installation timepath, as well as perhaps more consistent estimates of the total tidal resource capacity estimates for the UK, a longer term simulation may be interesting to conduct, particularly in light of the potential for 'legacy' effects. This relates to the possibility for economic impacts that persist long after the initial turbine installation expenditures have ceased, due to an increase in factor supplies of capital and labour (i.e. via labour supply in-migration and investment decisions). This could be important to policy makers considering the net economic impact of renewable energy projects, whose effects may persist beyond the duration of direct expenditures[46].

The results are of importance to UK and Scottish policymakers. If the UK's tidal resources are used for electricity generation, this will provide benefits in terms of the security of supply of energy, environmental obligations, as well as economic effects. The more developed are the backward linkages for the industry, the greater will be the impact of any domestic and international market, therefore the provision of appropriate government support mechanisms will be crucial in encouraging local production, the establishment of a technical knowledge base, and a skilled labour

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[46] Allan et al. (2008b) suggest that there would likely be such legacy effects associated with the establishment of a wave energy sector in Scotland.

supply. The analysis also suggests that it is the export market for tidal turbines that perhaps has the most potential to contribute to sustained economic growth in the UK, given the size of the worldwide resource and the associated international market for turbine commodities and technologies. It is reasonable to assume that a well-established domestic market is a necessary precursor to strong export demand, but it is likely that government policies aimed at promoting and supporting both the domestic and international development of the industry will generate far more substantial economic benefits in the long term, compared with policy initiatives that are focused purely on assisting the domestic market.

The very uneven spatial distribution of the resource across the UK also raises some important questions regarding the regional effects of the impact, and the corresponding implications for policy co-ordination and the division of policy instruments between the Scottish and UK governments. Much of the UK's tidal power resource is concentrated in Scottish waters, and this suggests that, assuming clusters of industrial activity develop close to the resource, a disproportionate share of the positive impact could occur in the Scottish economy. The Scottish and UK governments have already established distinctive energy policy priorities, owing to the different incentives for development of the industry. Given the differences in emphasis and intent that have emerged between these governments with regards to their objectives for tidal energy and renewable energy in particular, a more spatially-orientated analysis of the policy issue would provide an important input to decision-making in the policy arena.

Chapter 7

Conclusion

1. Summary and contribution of the research

The primary objective of this thesis is to consider the economy-wide impacts of a range of exogenous regional and national shocks, each of which relates to a current policy concern of the Scottish and/or UK governments. I use a CGE model for the research, which, I argue, allows for an important advance on current analysis of UK regional policy. This includes consideration of the period-by-period adjustment process of the economy following the shocks, and an examination of the nature of the constraints within which the economy operates. Additionally, for three of the four policy shocks that are analysed in this thesis, I identify both the interregional and national implications of the shock.

In Chapter 1 I outline the motivation for the thesis and in Chapter 2 I describe the theoretical underpinnings of CGE models, review key model features and applications in the literature and evaluate CGE modelling as a tool for policy analysis, vis-à-vis other modelling types. I find that CGE models can equip policy makers with a valuable tool for decision-making. The models can validate intuition about the likely economic effects of a policy change, or, conversely, bring to light unanticipated consequences of exogenous economic changes. They provide insight into how an economic shock works its way through an economy over time and through sectors and, in the case of interregional models, across regions. Thus they can help decision-makers to develop a more inclusive, rather than a purely local, perspective about the effects of a policy. I also note the weaknesses of the approach, and describe a ‘wish list’ of good practice techniques for minimizing the limitations.

In Chapters 3-6, I conduct a number of applications using CGE models of the UK economy. The first three of these analyses are conducted using an interregional CGE model of the UK, and the focus of these studies is to demonstrate the importance of the spatial impact of the exogenous economic change. I consider the regional and national effects of a broad-based regional demand- and supply-side shock in Chapters 3 and 4, respectively. In Chapter 5 I examine the impact of a regional demand shock on the environmental 'trade balance' between Scotland and the RUK, and evaluate the added-value of CGE relative to I-O analysis of the policy issue. In the final application, in Chapter 6, I use a single region CGE framework which is more highly disaggregated at the sectoral level. In this analysis, I investigate the potential economic impact of growth in the UK marine renewable energy sector at both a domestic and international level. Each of the applied analyses in Chapters 3-6 considers the impact of an exogenous shock to the regional or national economies, which relates to a specific and current policy objective of the Scottish and/or UK governments.

The need for a spatial disaggregation of the effects of a policy has been emphasised by empirical findings which suggest that the regional effects of exogenous shocks may be considerably different from the national average (Nijkamp et al., 1986, pp. 259 and 261; Miller and Blair, 1985, p. 63), and the results of this research reinforce the importance of the spatial aspect of regional policy evaluation. In Chapters 3 and 4, I demonstrate the existence of significant spillover effects for the non-target region following a specific policy-related regional demand and supply shock, respectively. The spillover effects are not consistent with 100% crowding out, such that the net national effects of the policies are non-neutral for both the demand and supply-side changes. The nature and magnitude of these spillovers are found to vary significantly depending on assumptions about the configuration of the labour market. For some scenarios, even the direction of the change in economic activity varies across the regions when the labour market closure is changed. Moreover, while target-region results are sensitive to alternative assumptions of how regional labour markets function, the effects on the non-target region prove to be even more so.

The findings of the research are therefore particularly important for policy-makers in the UK. In terms of regional development policies, the Treasury traditionally held the view that the national effects of regional policy were neutral: employment gains in one region were assumed to be displaced by an equal number of job losses elsewhere (HM Treasury, 1997). This meant that the focus of regional policy-making was on the redistribution of wealth and employment, rather than the pursuit of national economic gain. Partly as a result of this standpoint, there has been little emphasis on measuring the effects of regional policies on the non-target and national economies. More recently, however, the Treasury appears to have moved away from the view that regional development policies are accompanied by 100% crowding out, at least for supply-side policies. The Treasury now accepts that investment in skills and infrastructure at the regional level, aimed at improving competitiveness, for example, may affect national as well as regional economic activity (HM Treasury, 2003).

The findings of Chapters 3 and 4 resonate with this change in stance relating to supply-side public policy. In fact, the results go further to suggest that spillover effects are also important for demand-side policies. The research therefore provides an important contribution to the literature, which is underdeveloped in the treatment of the impact of regional policies on non-target regions and the nation as a whole. Moreover, an additional contribution of the research relates to the implications for policy design and evaluation in practice. By demonstrating the potential for non-target region and therefore national spillover effects of regional policy, the results imply that the size and sign of all spillover effects associated with a policy need to be investigated during policy design and evaluation. It is not always possible to identify a priori the direction or extent of a spatially-oriented policy change on the non-target region, as the Treasury's former position on regional policy would have suggested. Despite the UK government's recent acceptance of spillover possibilities, however, the ramifications for decision-making do not appear to have been widely appreciated, nor have appropriate adjustments to policy evaluation been made. There is no Treasury model that exists with which to test for policy spillovers and to assess the nature of interregional impacts. Moreover, even if the Treasury did possess such a model, the consistency, timeliness and degree of disaggregation of official UK interregional trade flow data are insufficient to allow detailed studies of a wide range of specific policy shocks on non-target and national economies. In this context, the research therefore highlights some of the theoretical and practical limitations of current regional policy-making in the UK.

In Chapters 5 and 6, I aim to reinforce the importance of a more comprehensive approach to policy evaluation by considering the potential regional and national impacts associated with more specific policy issues, which relate to aspects of UK energy policy. In Chapter 5, I demonstrate the added-value of CGE analysis over a particular I-O model by exploring the impact of a regional demand stimulus on the CO_2 'trade balance' between Scotland and the RUK. I consider the impact of a demand shock on the emissions embedded in trade between Scotland and the RUK, and I compare the results of an interregional CGE model of the UK with those of a comparable interregional I-O model. This is a key issue since there is presently a great deal of interest in accounting for carbon emissions at the regional, national and international level and whilst the Scottish and UK governments have each set CO_2 emissions targets, these commitments take no account of the emissions embedded in traded goods. However, the main contribution of this research is methodological, rather than substantive in nature. I argue that while I-O modelling can be a powerful accounting tool for analysing such issues, the CGE model, which possesses the main strengths of the I-O framework in terms of its multi-sectoral, system-wide framework, also allows more theory-consistent modelling of both demand and supply-side behaviour, for the case of a marginal change in activity. Furthermore, the CGE approach provides additional information for policy-making by tracking the adjustment path of the economy over time, and by highlighting the impact of alternative specifications of supply-side behaviour at the regional and national level on model results. Thus, by virtue of demonstrating the additional information content of a CGE analysis over a given I-O model, I highlight the added-value of such economy-wide modelling approaches for policy analysis, in this specific policy context. Although the environmental trade balance analysis is common in the I-O literature, the issue has not, to my knowledge, been considered before using a CGE model, in order to make use of the beneficial features of the framework for policy analysis, and it therefore makes an important addition to the existing literature. The results are qualified on a number of counts, however, most notably relating to the use of experimental data in the interregional I-O and SAM, as well as the insufficient level of disaggregation of the results for use in detailed analyses of the issue.

In Chapter 6, I consider a further aspect of UK energy policy: the commitment of the Scottish and UK governments to increasing the share of UK electricity consumption derived from renewable energy sources. Wind power has been the prevalent type of renewable energy development in the UK up to now, but other renewable technologies, such as tidal power, have attracted increasing attention from policy makers and investors in recent years, both in the UK and internationally. In Chapter 6 I consider the impact of an expenditure stimulus associated with an increase in domestic and international demand for tidal energy devices produced in the UK. To date, there exists no economy-wide analysis of the domestic and international demand stimulus associated with the development of specific renewable energy industries for the UK or internationally. The research thus makes a valuable contribution towards the knowledge base for energy policy analysis in the UK. I find that, based on a set of assumptions regarding the nature and magnitude of the expenditure path and the configuration of the UK labour market, the demand stimulus could potentially deliver a significant economic benefit to the UK, but that crowding-out effects associated with the shock mean that the impact varies substantially across the UK sectors, and that the net impact on economic activity falls far short of the initial demand stimulus. However, I acknowledge that in practice the actual extent of the deployment of tidal devices in the UK and the rest of the world, and therefore the total UK demand stimulus, will depend on a complex mix of technological, economic and political factors during the period considered.

The analysis of Chapter 6 is conducted using a national CGE framework for the UK economy, though an additional and important insight of the research relates to the skewed regional distribution of tidal resources in the UK. A disproportionately large share of the resource is located in Scottish waters and, assuming that clusters of economic activity develop in areas close to the resource, much of the expenditure stimulus could be concentrated in Scotland. This suggests that an interregional investigation of the effects would be valuable. In the absence of a suitably disaggregated base year dataset to conduct such analysis at present, the research in Chapter 6 is intended as a first step towards a more detailed interregional analysis. However, the results of earlier chapters provide important indications about the potential interregional effects of such a disproportionate stimulus to the UK economy. In Chapter 3, I find that the target-region effects that result from an exogenous export demand shock to the Scottish manufacturing sector can differ significantly compared to the other-region and national impacts, and that an important determinant of the regional effects include assumptions about how the labour market operates. In fact, for some labour market scenarios, whilst the effects on the target region and the national economy are positive, the non-target region effects are negative, even in the long term. The combined results of these analyses therefore suggest that the positive national impact of the demand stimulus to the tidal energy sector suggested by the research of Chapter 6 may conceal important, and diverse, effects at the regional level, and reinforce the need for sufficient data resources for interregional policy analysis.

Each of the applied analyses in Chapters 3 to 6 are particularly interesting in the context of a devolved policy framework in the UK, and the research also provides a crucial contribution to discussions of the nature of policy co-ordination between the devolved and national governments. The implication of devolved decision-making is that regional governments are entitled to pursue their own policy objectives, even if they differ from those of the national government. If, in the pursuit of these policy objectives, one region’s economic gain comes at the expense of another region’s economic loss, as is the case for some of the results in Chapters 3, 4 and 5, and if regional authorities have no incentive to incorporate other-region impacts into their individual objective functions, then this could be a potential source of inefficiency in policy decision-making. The results of the interregional analyses in this thesis, and the identification of distinct regional effects of policies, therefore suggest that there may be circumstances where policy co-operation is welfare-improving. However, effective policy co-ordination would entail the identification of other-region and national effects of regional policy, and the assignation of appropriate weights for these impacts. Therefore the key recommendation to develop from this research is that regional policy-making should entail identifying these impacts with a full, economy-wide interregional model of the UK, alongside the collection of more detailed and timely interregional trade flow data than those which are currently available.

2. Suggestions for future research

The analysis of this thesis could be extended in a number of ways. Each of the exogenous shocks imposed in this thesis are associated with costless government policies. Chapters 3 and 5 consider the effects of a broad-based, exogenous rest of world demand shock on the Scottish and RUK manufacturing sectors respectively. This is based on, for example, the Scottish government's objective to increase exports by improving Scottish competitiveness. However, I do not consider the additional impact of increased government expenditure on research and development in order to achieve this aim, or an increase in taxation in order to fund the policy, or any other policy change to represent the cost of the policy. Chapter 6 provides more specific detail on one potential source of an exogenous demand shock to the UK economy: an increase in domestic expenditures on tidal turbine equipment and installations, combined with an increase in rest of world demand for UK-manufactured tidal technologies. The increase in domestic and international demand is assumed to be associated with stated UK and international government targets for emissions reductions and a move towards renewable energy sources, but the implicit assumption is that the private sector funds these developments. Neither do I consider here the simultaneous impact of a price subsidy for renewable technologies to engineer this demand, for example, or the ring-fencing of funds for renewable energy developments that are sourced from carbon tax revenues. Similarly, for the supply-side shock that is conducted in Chapter 4, I assume that there is an increase in labour efficiency in the Scottish traded sectors, and that this represents the costless outcome of more effective policy-making at the regional level.

The reasoning behind the consideration of costless policies is twofold. The first is pedagogic. The size and complexity of CGE models means that identifying the features of the models which drive their results is often a difficult and demanding task. This can be especially true for interregional models, which have the added complication of interregional spillover and feedback effects. An iterative approach to simulations can therefore minimise the risk of the framework becoming a ‘black box’, and represents a responsible approach to policy analysis. In the presence of a single exogenous change to the model, the nature of the intersectoral and, where relevant, interregional responses of the economy can be much more easily understood, thus aiding tractability of the results. An appreciation of how the model outputs behave in response to a change in its inputs is of crucial importance to ensure best use of the model.

The second reason relates to the nature of policy analysis. Policy makers aim to assess the efficiency of policy interventions with respect to their effects. In doing so, a key objective of policy evaluation is to isolate the effects of the policy intervention in question as far as possible from the impact of all other influences of the economic environment, and this therefore requires analyzing the impacts of a policy in isolation. Certainly, policy makers often announce ‘policy packages’, such as ring-fenced fiscal interventions, though costless policies, assumed to be the result of efficiency savings, for example, also explicitly feature in government decision-making. Indeed, each of the costless regional policy shocks considered in Chapters 3 and 4 are exactly of the type that have been announced by the Scottish government, which is an active policy-making body, and which has limited revenue-raising powers.

In practice, however, such regional policies are unlikely to be entirely costless, and will require to be paid for either by the regional government, by the national government through regional transfers, or shared in cost by the region and the rest of the UK. An increase in productivity, for example, could be paid for through taxes to fund human capital augmentation or infrastructure construction. Thus a prudent approach to analysing policy changes in a CGE framework is to adopt an iterative method, incorporating additional exogenous changes to represent policy costs, and comparing and contrasting the results with those from previous simulations. In this way, changes in results can be attributed with confidence to the additional exogenous change, and its effect on the adjustment path of the economy. Important future research, therefore, would involve re-running the simulations involving the increases in export demand and productivity which are examined in Chapters 3 and 4 respectively, but in this case incorporating a mechanism to fund the demand–side or supply-side stimulus.

Similarly, in Chapter 6, I impose a costless exogenous demand shock that is associated with an increase in domestic and international demand for tidal energy technologies. An extension of this analysis would be to incorporate the cost of the domestic component of the demand stimulus, and could be based on the government's recent announcements on mechanisms for incentivising a switch to the use of renewable energy technologies such as tidal power. The UK government's 'Low Carbon Transition Plan' (Department for Energy and Climate Change, 2009b) proposes a tenfold increase in renewable energy capacity over the next decade, with the increase in renewable demand to be stimulated by measures such as the Renewables Obligation scheme (as discussed in Chapter 6, Sections 1 and 8), financial incentives for commercial developments, and feed-in tariffs for homeowners, which promote the sale of energy from household solar panels and wind turbines to the national grid. The Committee on Climate Change, an independent body that advises the government, is also expected to put forward a number of additional funding options to allow the government to achieve its carbon emissions targets, including a carbon tax on power generation, from which renewable energies such as tidal power would be exempt. Important further research would therefore involve simulating an exogenous economic stimulus, combined with a public expenditure or other shock, designed to represent the intended funding options being considered by the government[1].

A number of extensions of the energy policy analyses of Chapters 5 and 6 could be beneficial. In particular, it would be useful to apply the energy attribution techniques of Chapter 5 to the analysis of Chapter 6. In Chapters 5 and 6, I examine two particular issues that are relevant to current UK energy policy. These are ultimately related to (i) the regional and national economies' obligations to meet targets for CO_2 emissions reductions and (ii) the Scottish and UK governments' promotion of renewable energy technologies as a means of helping to achieve such targets. There is potential, however, for the outcome of the latter policy concern to offset the former to some extent. The Scottish government, in particular, has emphasised the growth opportunities for emerging renewable energy technologies such as marine renewables, both in terms of domestic and international demand. The analysis of Chapter 6 is motivated by this policy issue: here I investigate the economic impacts of such a stimulus to the marine renewable energy sector. The policy focus, however, which is essentially intended to encourage renewable energy installations in order to meet stated carbon emissions targets, is actually aimed at generating a demand stimulus in a sector which is energy-intensive in production. Thus if the policy outcome is to stimulate an export market for UK renewable energy devices, then the increase in activity in the production sector could offset to some degree any reduction in carbon emissions associated with a switch to renewable energy electricity provision. The net impact of the policy would depend on how much of the production sector's energy inputs are sourced from renewable, relative to non-renewable sources. An integrated energy-economy-environment CGE model, which incorporates the kind of attribution analysis used in Chapter 5, would be a useful framework for exploring such policy dilemmas.

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[1] The cost implications of some aspects of Scottish energy policy have been considered in a project commissioned by the Scottish government (Allan et al., 2008c), of which I am a co-author. In this project, an experimental energy-economy-environment CGE model of Scotland is used to model the impact of various climate change mitigation policies on the Scottish economy. The range of simulation scenarios are diverse, and include simulating the income effects of costly requirements on households to reduce their energy use.

This type of extended framework for the UK would also allow consideration of the possibility of 'double dividend'- type effects associated with government policies to help reduce pollution emissions via an increase in renewable energy demand. The 'double dividend' hypothesis suggests that a revenue-neutral environmental tax reform can have two types of benefits. The first is an improvement in the environment; the second is an increase in economic efficiency resulting from the 'recycling' of environmental tax revenues to reduce other taxes such as income taxes that distort labour supply and saving decisions. In this instance, I refer to a much looser interpretation of the 'double dividend' effect[2]. This relates to the idea that an increase in an environmental tax could be used to fund public expenditure on domestic renewable energy installations (such as tidal turbines), and that this may simultaneously improve both environmental and economic performance (and, indeed, could also alleviate policy concerns over the security of energy supply), whilst remaining revenue-neutral. An integrated CGE and pollution-attribution framework, using the attribution analysis of Chapter 5, would allow consideration of the conditions under which such 'double dividend'-type effects may occur.

In Chapter 6 I highlight the potential benefit of a more spatially disaggregated exploration of the chapter topic, given the skewed distribution of energy resources in Scotland, and the implications for policy co-ordination with the RUK authorities. An extended interregional framework could also be used to consider the consequences of Scotland's position as an energy exporter. The abundance of renewable energy resources in Scotland could provide an opportunity for the Scottish economy to play an important role as an electricity exporter to the RUK and, potentially, to surrounding

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[2] In the literature, the weak form of the 'double dividend' hypothesis suggests that that a revenue-neutral environmental tax reform can improve both the environment and the tax system. For example, a carbon tax could help reduce pollution emissions, with the revenues used to reduce other distorting taxes on labour or capital income. The strong form of the hypothesis asserts that the tax reform can lead to an increase in non-environmental welfare via, for example, an increase in employment as a consequence of a reduction in distortionary labour taxes. The concept of the 'double dividend' hypothesis was first introduced by Tullock (1967). Oates (1995) and Goulder (1995) also make notable contributions to the literature. Schob (2003) provides a recent survey of the issue.

countries, in the event of major investments in underwater cable networks. Such analysis could involve, for example, simulating the effects of production and construction expenditures associated with underwater cabling and extension of the UK grid capacity, alongside a potential increase in trade in electricity demand in Scotland. Indeed, for the analysis in Chapters 3-6 the degree of aggregation of the CGE models used may obscure important underlying relationships and model results. At present, issues with data availability and data consistency prevent further sectoral disaggregation for the AMOSRUK model, and regional disaggregation for the UKENVI model. However, as more official or experimental data become available in the future, additional disaggregation of the model data base – across sectors, regions or households, for example – would add value to the research.

Aside from the exploration of additional policy issues, a number of areas of the analysis could be addressed in order to increase confidence in the results. In Chapter 2 I outline the key limitations of CGE analysis, and methods to mitigate the constraints of the modelling approach. Foremost amongst these is the use of sensitivity analysis for the key parameter values and behavioural functions employed in the model framework. Inevitably, some degree of uncertainty surrounds the choice of parameter values and behavioural relationships in any model for policy analysis, and this holds true for the national and interregional CGE models used in this thesis. In Chapters 3-6 I conduct sensitivity analysis that relates to the configuration of the regional and national labour markets, in order to highlight the importance and nature of the uncertainty surrounding the exact configuration of the labour market. Although sensitivity analysis for all key relationships and parameter values is not feasible, due to the complexity of the model structure, there is much additional scope for parameter analysis in future research. Given the focus on stimulating the manufacturing sector via supply or demand-side shocks, and the importance of competitiveness factors in determining model results, systematic sensitivity analysis may be appropriate for the elasticities of substitution in production and trade parameters. Variation in relative price sensitivity may be introduced gradually into the system, in order to identify the conditions under which these factors have a significant impact on results. Turner (2009) conducts such an experiment in the national CGE framework UKENVI, so as to establish the conditions required for rebound effects to occur in response to increases in energy efficiency in the UK, and similar systematic sensitivity analysis would also be useful in the context of the AMOSRUK model simulations conducted in this thesis. Furthermore, the exact specification of the regional and national labour markets have been shown to be important in influencing results in the analyses presented in this thesis. This suggests that further estimation, data permitting, and/or sensitivity analysis relating to the parameter sizes and behavioural relationships in the labour market should be investigated.

A lack of rich data sets provides constraints to full econometric estimation of the AMOSRUK and UKENVI models, and these data limitations are especially relevant for parameterising regional characteristics. However, a number of new techniques have been developed for parameter estimation of regional CGE models in the presence of sparse and/or poor quality regional data. Adkins et al. (2003) use a Bayesian approach to estimate the production function parameters in a regional CGE model, using priors from more reliable national estimates. The authors estimate a Flexible Functional Form, which has the advantage of allowing for different substitution elasticities between pairs of factors, and for the possibility of complementarity. In the Bayesian approach, prior information about the likely value of elasticities or other parameters can be included into estimates of regional behavioural relationships, with more reliable and less scarce national data acting as a good source of this prior information, and such techniques could provide opportunities for more extensive calibration of CGE models in the future.

Additional contributions to the literature could be realised by making use of developments in macroeconomic theory in order to inform key structural extensions to the model framework. The interregional and national CGE models presented in this thesis have key limitations in terms of their model design. For example, they do not allow consideration of a wide range of imperfectly competitive market attributes[3] or forward-looking dynamics. Such real world phenomena could have significant effects on the impact of policy changes in practice, and therefore their absence from an evaluation framework could make resulting equilibria in the model inefficient. Notwithstanding the data limitations that would be associated with such technical changes, there have been a number of theoretical and practical difficulties associated with these issues, and this relates in particular to regional frameworks. There have been recent developments in the literature, however, which could act as a starting point for future research.

The incorporation of imperfectly competitive market features into the model framework could be of great consequence for detailed energy policy analysis. In reality, the presence of oligopolistic structures in energy markets means that production inefficiencies exist. As such, price exceeds marginal cost in the sector. It is likely that market imperfections are also present in the renewable energy market: renewable energy subsidies could bring about market distortions; there are significant economies of scale in production; and there are high barriers to entry, including high set-up costs. Many researchers introduce elements of imperfect competition into CGE models with a simple markup over marginal costs (See, for example: Cox and Harris, 1985; Gasiorek et al., 1992; Harrison et al., 1996, 1997). However, there are key practical difficulties involved in doing so. The first relates to the presence of heterogeneous demand. The I-O base of a CGE model implies the existence of several buyers of the same good, with different buyers having different elasticities of demand. This differs from the standard case of a unified demand curve. In the presence of imperfect competition, producers need to account for this heterogeneity in order to maximize profits. Where the producer is able to price discriminate between buyers, this is not a concern, but frequently this is not possible. This therefore raises the issue of how to determine the optimal markup when firms sell their goods at the same price to different types of buyers who have

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[3] Though I do investigate the impact of imperfectly competitive markets in relation to the labour market, for example via the wage bargaining labour market closures.

different elasticities of demand. Some researchers deal with this by assuming large group monopolistic competition, where the elasticities of demand for individual firms are identical and fixed (e.g. Gasiorek et al., 1992). However, for the energy industry, this may not be an appropriate assumption, due to the existence of barriers to entry in practice, which are not characteristic of monopolistic competition. More recently, Hoffman (2002) shows how to derive the optimal markup for a producer when there is more than one buyer and the buyers have different elasticities of demand. The author shows that the producer can use a weighted average of the different buyers' elasticities of demand in order to maximize profits, where the weights are equal to the share sold to each buyer. This technique could provide a good starting point for introducing imperfect competition into the energy sector in CGE models.

The second difficulty relates to the common practice of modelers using the final consumer's elasticity of demand to calculate the optimal markup. Although this provides a relatively straightforward way of estimating the optimal markup, using the Marshallian elasticity of demand also ignores the fact that in reality an increase in the price of a good reduces the income of the consumer and reduces the output of producers, who use the good as an input. In a partial equilibrium framework, this can be an acceptable assumption, but not so for general equilibrium analysis, where such linkages are important. Hoffman (2002) also provides guidance on how to derive general equilibrium, rather than Marshallian, elasticities of demand in models with Leontief production functions and for models with a more general production structure. Such methodological contributions provide important groundwork for future CGE model extensions.

An additional area of progress in the CGE literature is the incorporation of formal dynamic properties into the model structure. Recursive dynamic models of the type used in this research involve the linking of a sequence of single-period equilibria through stock-flow relationships, with the models being myopic in nature between periods, such that consumption, saving and investment choices abstract from future periods. However Devarajan and Go (1998) and Dissou (2002) suggest that models without forward-looking dynamics may fail to capture some of the dynamic costs and benefits associated with a policy change, which can lead to inaccurate and incorrect model results. Such costs include, for example, the costs of transitional unemployment or retraining labour. This could be particularly relevant for policies with long-run effects, such as those considered in this thesis[4].

Inter-temporal CGE models, on the other hand, explicitly incorporate forward-looking behavior, requiring all periods to be solved simultaneously. They allow for researchers to examine whether the policy change affects the rate of investment, the pace of technological change, and so forth. For example, in an inter-temporal CGE model structure, additional gains could be possible from improvements in productivity and from an increase in the rate of capital formation following a policy change. There are, however, a number of difficulties involved in incorporating dynamic features in an interregional framework, which is reflected in their absence in the literature. Aside from the data limitations of model parameterization, there are a number of theoretical constraints. The theoretical framework of many dynamic CGE models involves a model that is solved as a decentralized economy, with intertemporal optimizing households, and with savings and investment decisions separated (Abel and Blanchard, 1983). These models often assume that households maintain the financial requirements of the system, with household savings financing domestic investment and, ultimately, government and trade deficits. This requires the existence of a zero balance of payments constraint, so as to maintain financial sector sustainability. Whilst such a closure is uncontroversial in a national sense, the assumption is inappropriate for a regional framework, however. Regions tend to be more open than national economies, and typically belong to a nationally-integrated financial system. Thus the treatment of debt, and the role of savings, should differ from the usual national framework of dynamic CGE models. Lecca et al. (2009) develop an intertemporal forward-looking model that is able to take

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[4] Harrison et al. (2000) provides an overview of dynamic CGE models and the types of transitional effects that can be incorporated.

into account such regional features, by imposing an exogenously-determined savings rate so that no neoclassical balance of payments adjustment is required. Although the model is developed for a single region only, it represents a significant step towards an interregional framework, in an area of the literature that is not well developed at present.

A final future research opportunity relates to the potential for more explicit recognition of policy-making in the context of a decentralized government. In the AMOSRUK and UKENVI models, as in many CGE applications, the government is assumed to be passive. However, in the context of a devolved policy-making framework, with preferences over outcomes that can differ substantially for each authority, it could be useful to consider regional policy outcomes under alternative institutional arrangements for negotiating policy priorities or objectives, or interregional policy agreements. One potential area that could be useful to explore is the integration of CGE models, of the type used in this analysis, which model the impacts of specific policies, with formal bargaining models of the negotiations over these policies. Pinto and Harrison (2003) consider multilateral, multidimensional policy negotiations over CO_2 abatement policies. They use a CGE model to reveal preference functions, which are then used in a multilateral bargaining game. Such research topics would provide an interesting welfare-based direction for future research. Although the analysis is appealing at a multi-country level, a UK level study would be worthy of doing, in light of the distinction in the policy preferences of the UK regional governments.

The type of model extensions described above would likely be non trivial and associated with theoretical difficulties, alongside data and other practical limitations. Furthermore, there always exists a trade-off between the complexity of models which better replicate real world phenomena but which may be associated with additional uncertainty regarding specification and loss of model tractability, and the simplicity of models which aid understanding but which risk being under identified. Notwithstanding this, the evolution of CGE modelling methods, particularly relating to influences from the new generation of macroeconomic models and their associated estimation techniques, has opened up a range of research development opportunities, and the technique is therefore likely to make a crucial contribution to policy-making in the future.

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APPENDIX A: The AMOSRUK model

The AMOS and AMOSRUK models were developed by Harrigan et al. (1991) and McGregor et al. (1996a) respectively. The model description provided here is close to the basic account of the AMOS and AMOSRUK models which features in these papers and others, such as Gillespie et al. (2001a, 2002). However, I provide a more detailed description of the model framework here for the purpose of completeness.

A.1 Model description

AMOSRUK is an interregional CGE model of the UK economy. There are two endogenous regions in the model framework, Scotland and the RUK, and one exogenous region, the ROW. The Scottish economy accounts for around 8.5% of total UK population, employment and output, and the remainder is attributed to the RUK region. Each of the two endogenous regions is designed in a similar manner to that in the single region model of the Scottish economy, AMOS (Harrigan et al., 1991). In the interregional AMOSRUK version, however, the individual regions are linked through trade and potential migration flows, and the relationship between the regions is generally influenced by endogenous changes in prices, wages and activity in each region[1].

There are three transactor groups in each region, namely households, firms and the government; three commodities and activities (manufacturing, non-manufacturing traded and sheltered sector activities); and one exogenous transactor (the ROW). Commodity markets are taken to be competitive, and financial flows are not explicitly modelled (the assumption being that the UK is a price taker in world financial markets). There are four main components of final demand: household consumption, government expenditure, exports and investment. Consumption is a linear homogeneous function of real disposable income; government expenditure is exogenous; and interregional and

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[1] In contrast, in the single region AMOS model, prices, wages and activity are endogenous in Scotland, whilst prices, wages and activity in the RUK are exogenous.

international exports (and imports) are determined via an Armington link[2], and are therefore relative-price sensitive. Whilst non-price determinants of export demand from the ROW are taken to be exogenous, export demand to the other UK region is fully endogenous, depending not only on relative prices, but also on the structure of all elements of intermediate and final demand in the other region. The role of investment is discussed later in this appendix.

The AMOSRUK framework offers a range of modelling choices corresponding to: model closures and constraints; the specification of key parameter values and functional forms; and the time period of analysis. AMOSRUK mode users can consider various model set-ups and simulation scenarios without recompiling the model. The construction of model frameworks and operation of simulations is enabled by working through a number of menus and data-entry screens. The process involves: selecting a model structure by defining the closures, functional forms and parameter values of the model; calibrating the model on the base year data set; simulating an exogenous shock to the model by exogenously changing one (or more) of the model variables; solving the model; and retrieving the solution results. Calibration of the model is automatic, and alternative model structures and simulation scenarios can be combined freely.

The high degree of flexibility within the framework allows the modeller to easily consider and compare not only the model outcomes that result from different policy changes within the same models, but also the results of the same policy simulation that are generated from models with differing structural characteristics. This aspect of the modelling framework makes it particularly useful for policy analysis, since assumptions regarding key features of the economy, such as the characteristics of the regional labour markets, for example, can greatly affect the outcome of policy evaluation exercises. The model also offers the option of long-run only or period-by period simulation results. In

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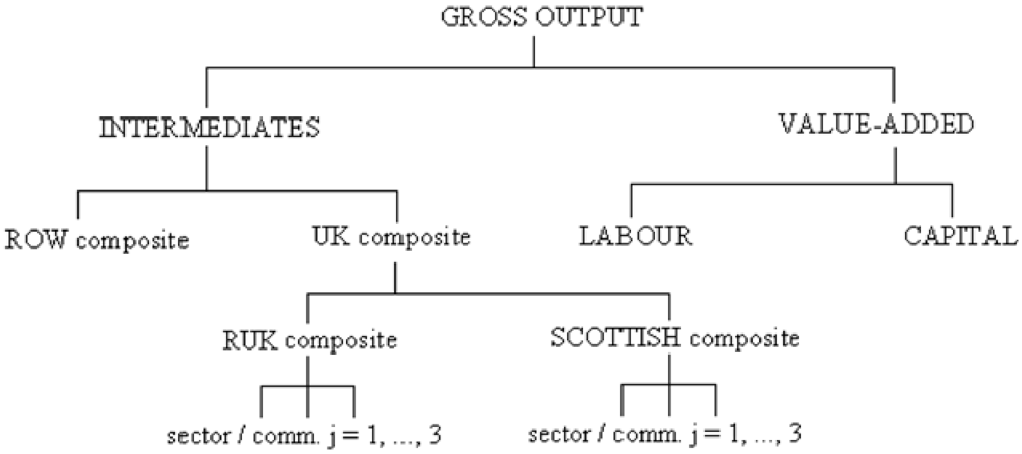
[2] Armington (1969).

this thesis, I focus on multi-period simulations throughout, providing further insight into the adjustment process of the economy following an exogenous shock.

A key feature of the model is that, regardless of how it is configured, cost minimisation in production is imposed, with the existence of multi-level production functions. These are of the constant elasticity of substitution (CES) form, so that there is input substitution in response to relative-price changes[3]. In production, local intermediate inputs are combined with imports from the other region and the ROW via an Armington link (Armington, 1969). This composite input is then combined with labour and capital (value-added) to determine each sector's gross output. Figure A.1 illustrates the production structure of the AMOSRUK model.

Figure A.1 Production structure of each sector in the 3 sector/commodity AMOSRUK framework



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[3] Production functions at each level of the production hierarchy can be CES, Cobb-Douglas or Leontief. In this paper CES production functions are imposed throughout , with the exception of the very bottom level of the production function hierarchy, where commodity substitution at the regional level is determined by Leontief functions.

In this thesis, I perform period-by-period simulations so as to illustrate the adjustment process of the regional and national economies in response to an exogenous shock. During each individual time period of the multi-period simulations, the aggregate capital stock remains fixed, as do the regional and sectoral capital stocks, and commodity markets clear continuously. However, an important feature of the AMOSRUK model is that capital stocks are updated between periods, according to a simple capital stock adjustment mechanism. Investment is equal to depreciation plus some fraction of the difference between the desired and actual capital stock, where desired capital stock is a function of commodity output, the nominal wage and the user cost of capital. This capital accumulation process corresponds with a simple theory of optimal firm behaviour given the assumption of quadratic adjustment costs. Desired capital stocks are determined on cost-minimisation criteria and actual stocks reflect last period's stocks, adjusted for depreciation and gross investment. The economy is assumed initially to be in long-run equilibrium, where desired and capital stocks are equal. In the long run, capital stock is optimally adjusted. For all of the simulations carried out in this analysis, the capital stock updating mechanism is active.

There are no changes to the national population by means of international migration or a natural increase in population. Regional populations are constant in each individual time period, and the model allows an option for the population to be updated and adjusted between periods via interregional migration. When interregional migration is allowed for, full flow equilibrium is imposed in the long run. In some of the simulations carried out in this analysis, the migration function is incorporated.

There are a number of labour market configurations available within the AMOSRUK framework, and this paper considers those which reflect popular views about the operation of regional labour markets that are prevalent in the literature. Each region exhibits endogenous participation and perfect sectoral mobility. The different labour market configurations incorporate alternative assumptions regarding regional wage determination, and existence of labour supply adjustments by means of interregional migration. More details of the labour market scenarios are provided in each chapter to which they are relevant, and are repeated in Appendix B for ease of reference.

By incorporating various assumptions regarding the characteristics of the regional and national labour markets, in this thesis I consider the impact of the existence of a national population constraint. For the purposes of the analysis, a region is defined as having an effective long-run population constraint when an increase in regional employment leads to an increase in long-run regional real wages. The different labour market configurations represent alternative views on regional wage determination and interregional labour supply flows. These alternative visions of the labour market therefore vary the operation and spatial impact of the population constraint, primarily via their effect on wage-setting. For example, when the regional labour market is determined by a bargaining relationship, a tightening of the labour supply is associated with an increase in the regional real wage and a decrease in competitiveness, thereby characterising the existence of a population constraint. The existence of interregional migration, however, can ease this labour market pressure, in this example by attracting net-inmigration to the region.

By incorporating this national population constraint, the model framework allows me to examine the supply side effects that can be associated with an exogenous policy change on the economy, and how different types of population constraint can affect the nature of spillover effects to other regions. However, depending on the extent of positive spillover effects to the other region as a result of increased interregional trade flows, for example, however, it may be the case that there are net positive spillover effects to the other region. In this sense, the extent and nature of a population constraint is potentially an important concern for regional policy analysis. The use of a CGE model in favour of, for example, I-O analysis allows me to identify the different types of supply-side effects that are associated with each of the labour market configurations.

In addition, macroeconomic constraints exist at the national level, though these are simplistic in nature. It is assumed that the government operates a fixed exchange rate regime and that interest rates are exogenous to the national economy. Alternative configurations are available for interest rate and exchange rate determination, though these are not explored in this paper[4]. The AMOSRUK model also provides the opportunity to impose constraints on the regional balance of payments and on public sector net transfers to the region. However, in this analysis, no constraints are imposed on the public sector budget.

The basic data set for the model is an interregional SAM for 1999. This dataset provides an overview of the Scottish and RUK economies for that year, and highlights the linkages amongst the sectors and regions, and their relative size. The SAM is an augmented I-O table with transfer payments between economic agents and factors of production[5]. It covers all intra-regional, interregional and international transactions within the economy that year. The structural data embedded in the SAM are used to ascribe actual values to some of the parameters of the functional forms in the model system (for example the relative size and import intensity of sectors). Other parameter values are determined exogenously (for example the migration function parameters and elasticities of substitution), drawing from existing literature. A final set of parameter values are determined through calibration of the model. All econometrically parameterised relationships have been established using annual data, so that each 'period' in the model relates to a single year.

For the simulations, the main parameter values are as follows: the elasticity of substitution in the CES production functions is set at 0.3 (Harris, 1989)[6] and the

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[4] McGregor et al. (1996a) discuses some of these options.

[5] The construction of an interregional UK SAM is a considerable exercise. The constraints involved relate to both regional data availability, as well as to the consistency of the data for the regions for which IO tables are published. Allan et al. (2004) provides details on the construction of the 1999 SAM that is the dataset for this AMOSRUK version.

[6] This is consistent with more recent estimates of the elasticity of substitution between capital and other factors of production in the UK. Barnes et al. (2008) estimate an elasticity of substitution in the region of

Armington assumption is applied to both interregional and international trade with an elasticity of substitution of 2.0 (Gibson, 1990). The parameter determining the speed of adjustment from actual to desired capital stock is set at 0.5, following econometric work on the determination of investment in the Scottish economy.

A.2 Model listing

Table A.1 presents a condensed version of the period-by-period AMOSRUK model used in this analysis, with the equations provided in general form. Variables, superscripts and subscripts are listed at the end of this appendix. Harrigan et al. (1991) provides a full listing of the AMOS model. In practice, the exact model set-up is determined by the model user, in their choice of functional form for production or for composite commodities, between Leontief, Cobb-Douglas or CES and so forth. This determines the specific choice of the output price and the input demand functions.

In this model listing, there are assumed to be two regions, *x* and *y*. For many equations specifying the characteristics of region *x*, a corresponding equation applies for region *y*. In order to report this summary version of the model, a number of simplifications are made. These relate to the model description only, and are not applied in practice to the model itself:

(i) intermediate demands are suppressed throughout. That is, only primary factor demands are reported for the determination of prices, and only final demands are reported for the determination of commodity demand.
(ii) many of the income transfers between transactor groups are suppressed.
(iii) taxes are ignored.

0.32 to 0.42 for the UK. In the Bank of England Quarterly Model, which is the macroeconomic model developed for use in preparing the Monetary Policy Committee's (MPC) quarterly UK economic projections, the parameter is set at 0.317 (Harrison et al., 2005). Although in the US the elasticity of substitution between capital and labour is often estimated at close to unity (e.g. Adkins et al., 2003), some estimates are close to the UK value of 0.3 used in this analysis (e.g. Chirinko et al., 2004).

(iv) time subscripts are suppressed.

Equation A.1 describes the determination of commodity value-added prices: pv_i^x represents the value-added price in sector i in endogenous region x. It is assumed that each of the three commodities is produced by a perfectly competitive industry in each region. The three commodities/industries are the manufacturing, non-manufacturing traded and sheltered sectors. The sheltered sector includes those service sectors which engage in very low levels of extra-regional trade.

There is linear homogeneity in the production of value added and an implied assumption of cost minimisation and zero profits. Thus value-added prices are determined by corresponding industry cost functions, and the value-added price is a linear homogeneous function of the regional factor prices, w_n^x and w_k^x, which are the wage rate and the capital rental rate, respectively. Likewise, commodity prices in the regions, p_i^x, is a linear homogenous function of the value-added price and the vector of intermediate prices. The latter is made up of the vector of other commodity prices in that region, $\underline{p}_{j-i}^x$, the vector of commodity prices in the other region, $\underline{p}^y$, and the vector of the domestic currency prices of foreign imports, $\underline{\bar{p}}^w$. Equation (A.2) describes this relationship. Equations A.3 and A.4 provide the regional consumer and capital indices, cpi^x and kpi^x, respectively. These are the weighted sums of all the commodity prices in the system. Equations A.5 and A.6 describe the cost-minimising demand functions for the factors capital and labour. In each industry in each region, the demand for labour, N_i^x and the demand for capital, K_i^x, is a function homogenous of degree one in regional industry output, Q_i^x, and of degree zero in the regional factor and the value-added and commodity price. Within each region, perfect sectoral mobility of labour and capital is assumed. The capital rental rate in each sector in each region is determined by equating capital demand, K_i^x, with the existing capital supply, K_i^{sx} (Equation A.7).

Regional nominal household income, Y^x (Equation A.8) is the share of the labour and capital income generated in the region, φ_n^x and φ_k^x respectively, plus welfare transfers associated with unemployment. The extent of transfers depend on the number of unemployed people in the region, $L^x T^x u^x$, multiplied by the unemployment benefit f. The demand for commodity i in region x, Q_i^x, is determined by Equation A.9, and is equal to the sum of consumption, intermediate, investment, and government demand, and interregional and international export demands. These elements are: C_i^x, J_i^x, I_i^x, G_i^x, X_i^x, and X_i^{xw}, respectively. The individual components of commodity demand are themselves denoted by Equations A.10 to A.15. The aggregate consumption demand (Equation A.10) is linear in regional real income and homogenous of degree zero in all nominal variables. A representative transactor approach is adopted. Regional data constraints mean that household income is not disaggregated by income group. Intermediate demand (Equation A.11), is homogenous of degree zero in regional value-added and all commodity prices, and is a linear function of all regional outputs. Investment demand is the sum of investment in each region in each industry, which is equal to the change in capital stock adjustment in each regional industry, ΔK_i^x (Equation A.12). The vector of ΔK_i^x values is transformed into investment demands for the output of sector i via a fixed-coefficient capital matrix, which contains elements b_{ij}^x. The vectors of own-region, other-region and world commodity prices are also determinants of the investment demand equation. These reflect the proportion of activity that remains in the region rather that being diverted elsewhere via interregional or international imports, driven by changed price competitiveness. Government demand is a fixed proportion, α_i^x, of total (exogenous) UK government expenditure, $\overline{G}^N$ (Equation A.13).

Equations A.14 and A.15 describe interregional and international export demands for industry i, respectively. The former depends on consumption, intermediate, investment and government demand for industry i in the other region, y, and the relevant price vectors. The latter is a homogeneous function of degree one in foreign demand, $\overline{D}^{w}$ (which is exogenous), and zero in regional and foreign prices.

Equations relating to the between-period updating functions that are available for capital stocks and population are described in Equations A.16 to A.19. Actual capital stock in each regional industry i in each time period, t, $K_{i,t}^{sx}$, is equal to the capital stock in regional industry i in the previous time period, $t-1$, less depreciation (δ_i^x) and plus gross investment ($K_{i,t-1}^{sx}$) in the previous time period, $t-1$ (Equation A.16). Therefore capital investment made in period $t-1$ adds to capacity in period t. Equation A.17 relates to the capital-stock-adjustment process. The desired capital stock is equal to the capital demand equation (Equation A.6), but for the substitution of the final term, the risk-adjusted user cost of capital (ucc), in place of the actual capital rental rate. This means that when the capital rental rate exceeds the risk-adjusted user cost of capital, the desired capital stock is greater than the actual stock. In such a scenario, capital accumulation occurs until the risk adjusted user cost of capital and the capital rental rate are equalised. Thus in long run equilibrium, the capital rental rate across all sectors equals the corresponding risk-adjusted user cost. The value of the user cost of capital depends on the interest rate, the depreciation rate, the relevant tax and subsidy rates, and the regional capital price index, though since interest, tax and subsidy rates are held constant in the simulations, changes in the regional capital rental rates are determined only by changes in the regional capital price index (Equation A.18). Total capital stock adjustment (or investment) in each period, then, is equal to a fraction, λ, of the difference between desired and actual capital stocks, plus depreciation (Equation A.19), where λ is the capital stock adjustment parameter.

Table A.1: Condensed Model Listing

Value-added prices	$pv_i^x = pv_i^x(w_n^x, w_k^x)$	(A.1)
Commodity prices	$p_i^x = p_i^x(pv_i^x, \underline{p}_{j-i}^x, \underline{p}^y, \overline{\underline{p}}^w)$	(A.2)
Consumer price index	$cpi^x = \sum_i \theta_i^{xx} p_i^x + \sum_i \theta_i^{xy} p_i^y + \sum_i \theta_i^{xw} \overline{p}_i^w$	(A.3)
Capital price index	$kpi^x = \sum_i \gamma_i^{xx} p_i^x + \sum_i \gamma_i^{xy} p_i^y + \sum_i \gamma_i^{xw} \overline{p}_i^w$	(A.4)
Labour demand	$N_i^x = N_i^x(Q_i^x, p_i^x, pv_i^x, w_n^x)$	(A.5)
Capital demand	$K_i^x = K_i^x(Q_i^x, p_i^x, pv_i^x, w_k^x)$	(A.6)
Capital rental rate	$K_i^x = K_i^{sx}$	(A.7)
Household income	$Y^x = \varphi_n^x N^x w_n^x + \varphi_k^x K^x w_k^x + L^x T^x u^x f$	(A.8)
Commodity demands	$Q_i^x = C_i^x + J_i^x + I_i^x + G_i^x + X_i^{xy} + X_i^{xw}$	(A.9)
Consumption demand	$C_i^x = C_i^x(\underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w, Y^x)$	(A.10)
Intermediate demand	$J_i^x = J_i^x(\underline{Q}^x, \underline{pv}^x, \underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w)$	(A.11)
Investment demand	$I_i^x = I_i^x(\underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w, \sum_j b_{ij}^x \Delta K_j^x)$	(A.12)
Government demand	$G_i^x = \alpha_i^x \overline{G}^N$	(A.13)
Interregional export demand	$X_i^{xy} = X_i^{xy}(\underline{p}^x, \underline{p}^y, \overline{\underline{p}}^w, \overline{G}^N, \underline{J}^y, \underline{Q}^y, Y^y)$	(A.14)
International export demand	$X_i^{xw} = X_i^{xw}(\underline{p}^x, \overline{\underline{p}}^w, \overline{D}^w)$	(A.15)
Capital stock	$K_{i,t}^{sx} = (1-\delta_i^x)K_{i,t-1}^{sx} + \Delta K_{i,t-1}^x$	(A.16)
Desired capital stock	$K_{i,t}^{*sx} = K_{i,t}^{*sx}(Q_i^x, p_i^x, pv_i^x, ucc^x)$	(A.17)
User cost of capital	$ucc^x = ucc^x(kpi^x)$	(A.18)

Investment	$\Delta K^{x}_{i,t} = \lambda(K^{*sx}_{i,t} - K^{sx}_{i,t}) + \delta^{x}_{i} K^{sx}_{i,t-1}$	(A.19)
National population	$\overline{L}^{N} = L^{s} + L^{r}$	(A.20)
Regional population	$L^{s}_{t} = L^{s}_{t-1} + m^{s}_{t-1}$	(A.21)
Migration	$m^{s}_{t} = m^{s}\left[\frac{w^{s}_{t}}{cpi^{s}_{t}}, \frac{w^{r}_{t}}{cpi^{r}_{t}}, u^{s}_{t}, u^{r}_{t}, L^{s}_{t}\right]$	(A.22)
Unemployment rate	$u^{x} = \frac{L^{x}T^{x} - \sum_{i} N^{x}_{i}}{L^{x}T^{x}}$	(A.23)
Bargaining	$w^{x}_{n} = w^{x}_{n}(u^{x}, cpi^{x})$	(A.24)
Quasi IO	$w^{s}_{n} = \beta^{x} cpi^{x}$	(A.25)
Wage Spillover	$w^{x}_{n} = w^{y}_{n}$	(A.26)

Endogenous variables:

cpi: consumer price index

kpi: capital price index

m: Scottish immigration

p: commodity price

pv: value-added price

u: unemployment rate

ucc: user cost of capital

w_n: nominal wage rate

w_k: capital rental rate

C: consumption

D: foreign demand

G: government expenditure

I: investment demand

J: intermediate demand

K: capital demand

K^s: capital supply

ΔK: capital stock adjustment

L: population

N: employment

Q: output

X: exports

Y: household income

Parameters and exogenous variables:

b: capital coefficient

f: benefit payment per registered unemployed

D: rest of the world demand

T: participation rate (do we need this?)

α: government expenditure coefficient

β: real wage coefficient

δ: depreciation rate

φ: regional share of factor income

θ: consumption expenditure share

γ: capital expenditure share

λ: capital stock adjustment parameter

Subscripts:

i, j: sectors

k: capital

n: labour

t: time

Superscripts:

r: rest of the UK

s: Scotland

w: rest of the world

x, y: generic regional identifiers

Functions:

$m(.)$: migration function

$p(.), pv(.)$: cost function

$ucc(.)$: user cost of capital function

$w(.)$: wage curve

$C(.)$: Armington consumption demand function

I(.): Armington investment demand function

$J(.)$: Armington intermediate demand function

$K(.), N(.)$: factor demand functions

$X(.)$: Armington export demand function

Notes:

- A bar above a variable indicates that this variable is exogenous for the purposes of the simulations) i.e. a bar over a variable denotes exogeneity.
- Underlined variables are vectors whose elements are the sectoral values of the corresponding variables. Where the subscript $j-i$ is used, this represents a vector of all sectoral values, excluding sector i.
- A starred variable indicates desired value.
- Implicit time subscripts apply to all the variables, and these are stated explicitly only for the relevant updating equations (Equations A.1 to A.10 in Table A.1).

APPENDIX B: Alternative visions of the labour market

In evaluating the full spatial impact of a demand shock, in this study I focus on a population constraint that can operate at the regional or national level. I define a region as having an effective long-run population constraint when an increase in regional employment leads to an increase in long-run regional real wages. Thus where an increase in employment is not directly associated with an increase in long-run real wages - for example due to the presence of fixed real wages or in-migration - no effective long-run population constraint exists. The main impact of the constraint feeds through to the economy via its effect on wage setting. For example, where the regional real wage is determined by a local bargaining process, a rise in employment leads to an increase in the regional real wage and a reduction in competitiveness. Interregional migration can, however, ease this labour market pressure, in this example by attracting net in-migration. In the simulations to follow, my objective is to determine the significance of the population constraint in influencing the spatial impacts of the policy-related shock. I consider five labour market scenarios - summarised in Table B.1. Each of these is intended to represent a stylised version of conventional labour market configurations that are common in the labour market and regional macroeconomic literature.

Table B.1 Simulation scenarios

	Population	**Regional Wage Setting**		**Effective Long-Run Population Constraint**	
		Scotland	**RUK**	**Regional Level**	**National Level**
Quasi IO	Fixed at the regional level	Fixed real wage	Fixed real wage	No	No
Regional Bargaining	Fixed at the regional level	Bargaining	Bargaining	Yes	Yes
Flow Migration	Fixed at the national level	Bargaining	Bargaining	No	Yes
Wage Spillover (1)	Fixed at the regional level	Adoption of RUK nominal wage	Bargaining	Yes (RUK) No (Scot)	Yes
Wage Spillover (2)	Fixed at the national level	Adoption of RUK nominal wage	Bargaining	Yes (RUK) No (Scot)	Yes

B.1 Quasi I-O

The first scenario incorporates fixed real wages in both the Scottish and RUK economies. There is no interregional migration of the labour force, so that regional employment is determined solely by regional labour demand. This configuration involves no effective population constraint at either the regional or the national level. Increased employment is met by increased regional labour market participation, with no change in real wages, so neither region suffers adverse competitiveness effects generated specifically through the labour market as export demand expands. The nominal wage might change but only in response to changes in the regional consumer price index (CPI). Capital fixity dictates supply restrictions, so that marginal costs and prices rise in the short-run as output expands. Over time, however, investment optimally adjusts capital stocks, relaxing capacity constraints, and ultimately the economy operates like an extended I-O system (McGregor et al., 1996b). In this scenario, the economy is capital-constrained in the short -run, though in the long-run there are no supply-side constraints. In the long-run therefore the only elements to restrict economic activity are real government expenditure (which is assumed fixed) and world demand for exports. Consequently, such closures can lead to significantly large effects emerging from small disturbances. Hence this configuration is used only for the purposes of benchmarking. Although I appreciate the unrealistic and theoretically problematic nature of the closure, the results nevertheless offer important insights into the forces at work during the adjustment process of the regional economies.

B.2 Regional Bargaining

The second simulation scenario involves a set-up where population is fixed in each region as before, but differs from the Quasi I-O configuration in that wages are determined by a bargaining process. The particular bargaining function adopted is the econometrically-parameterised relationship identified by Layard et al. (1991):

$$\ln\left[\frac{w^I}{cpi^I}\right] = \beta^I - 0.113\ln u^I \qquad \text{(B.1)}$$

where:

w is the nominal wage rate

cpi is the consumer price index

u is the unemployment rate

β is calibrated to ensure that the model replicates the base year data set, and

the I superscript indicates the region.

A population constraint operates in each region in this configuration. In both regions, real wages reflect the tightness of the regional labour market, measured as inversely related to the regional unemployment rate (Minford et al., 1994). Empirical support for this wage curve is widespread across countries, including for the UK, and in a regional context[1]. This configuration is intended to reflect the notion of a conventional 'wage curve' operating at the level of the region.

B.3 Flow Migration

The third model scenario involves real wage bargaining at the regional level, as in the previous Bargaining set-up, but also introduces interregional migration to allow for population adjustment. Migration flows in one period serve to update the population stock in the next period. The Scottish rate of in-migration is positively related to the Scottish/RUK ratio of the real consumption wage and negatively related to the Scottish/RUK ratio of unemployment rates, in the spirit of Harris and Todaro (1970)[2].

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[1] See, for example, Blanchflower and Oswald (1990, 1994). More recent empirical evidence also suggests that the wage curve is still relevant to the UK economy, including in a regional context: see Barth et al. (2002), Blanchflower and Oswald (2005) and Montuenga et al. (2003).

[2] Harris and Todaro (1970) suggest that in-migration will occur to a local area (of developing countries) if (among other factors): wages increase, unemployment decreases or job creation increases, thereby increasing expected income in that area.

The specific form of this equation is in accordance with the econometrically parameterised interregional migration function of Layard et al. (1991):

$$\ln\left[\frac{m^S}{L^S}\right] = \delta - 0.08\left[\ln u^S - \ln u^R\right] + 0.06\left[\ln\left[\frac{w^S}{cpi^S}\right] - \ln\left[\frac{w^R}{cpi^R}\right]\right] \qquad \text{(B.2)}$$

where:

m is net-inmigration

L is population

δ is a calibrated parameter that ensures zero net migration (the equilibrium condition) for the base year data, and

S and R indicate Scotland and the rest of the UK respectively.

The topic of interregional migration in the UK has been an important one lately, with some authors proposing that native workers are finding it increasingly attractive to migrate to other areas in the UK in search of employment, as a result of competition with international migrant workers concentrated in areas such as the South of England (e.g. Hatton and Tani, 2005). Indeed Biswas et al. (2008) find that interregional migration in the UK has been significant in recent years (including between Scotland and the RUK), and has been increasing over time. Several micro- and macroeconomic factors have been put forward as determinants of UK interregional migration, with a number of studies suggesting that the Harris and Todaro-type migration function is relevant to the UK labour market[3].

In this set-up, the presence of migration allows for a unified national labour market: an increase in regional demand lowers regional unemployment and increases the real wage,

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[3] For example, Hughes and McCormick (2000) find that relative regional wages in the UK significantly influence migration between regions, and Pissarides and Wandsworth (1989) find that the level of regional unemployment significantly affects the probability of migration for an individual. Also, studies for the US include Treyz et al. (1993), who find that net migration is significantly related to, among other factors, relative employment opportunities and relative real wages.

inducing migratory flows into that region. In long-run equilibrium, the presence of migration re-imposes the original ratio of regional wage and unemployment rates (see Appendix B). In this scenario, the population constraint works only at the national level; migration eases labour market pressures for one of the two regions.

B.4 Wage Spillover (1) and (2)

In the Wage Spillover cases the RUK acts as the lead region and Scotland as the follower. Real wages in the RUK are determined by regional bargaining, as in Equation (B.1), while the Scottish economy accepts the nominal wage that is set by the RUK. This labour market set-up is intended to incorporate an interregional variant of the traditional Keynesian macroeconomic vision of a region in which nominal wages are fixed. This has often been motivated in terms of a national bargaining system. In the present case, Scottish nominal wages are not fixed, but they are determined outwith the region. The set-up captures the scenario whereby unions negotiate at the national level, and the outcome of the bargaining process feeds through to the regions, who are nominal wage takers[4]. Wage Spillover (1) incorporates no interregional migration, whilst in Wage Spillover (2), interregional migration is allowed for, according to Equation (B.2).

In the Scottish region, there is essentially no population constraint, since regional wages do not directly respond to regional labour market pressures. In the RUK region, however, there is an effective population constraint, since nominal national wages reflect the tightness of the labour market in the RUK. The UK economy as a whole is therefore population constrained.

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[4] This labour market configuration also incorporates the notion of inflationary wage spillovers, whereby inflationary wage pressures can differ across regions of the UK and wage pressures in one ‘lead’ region, such as the South East of England, can influence wages in other regions. A number of authors have considered the extent to which wages in one region of the UK are influenced by wages set in other regions, including Manning (1994) and Molho (1982). Armstrong and Taylor (2000) suggest that nationally bargained wages, and the corresponding wage rigidity that this introduces to regional labour markets, could be one explanation, amongst others, for regional unemployment differentials across the EU (pp. 170-171).

APPENDIX C: Interregional migration and the long-run ratio of regional wage and unemployment rates

This appendix demonstrates that the existence of interregional labour migration works to re-impose the original ratio of regional wage and unemployment rates following a disturbance. In Appendix B (and also in Chapters 3, 4 and 5), I define the regional bargaining function (Layard et al., 1991) as:

$$\ln\left[\frac{w^I}{cpi^I}\right] = \beta^I - 0.113\ln u^I \qquad \text{(B.1)}$$

where:

w is the nominal wage rate

cpi is the consumer price index

u is the unemployment rate

β is calibrated to ensure that the model replicates the base year data set, and

the I superscript indicates the region.

And the interregional migration relationship as:

$$\ln\left[\frac{m^S}{L^S}\right] = \delta - 0.08\left[\ln u^S - \ln u^R\right] + 0.06\left[\ln\left[\frac{w^S}{cpi^S}\right] - \ln\left[\frac{w^R}{cpi^R}\right]\right] \qquad \text{(B.2)}$$

where:

m is net-inmigration

L is population

δ is a calibrated parameter that ensures zero net migration (the equilibrium condition) for the base year data, and

S and R indicate Scotland and the rest of the UK respectively.

In the AMOSRUK model, a zero net migration condition exists in equilibrium. Using Equation (B.2), then, in equilibrium,

$$0 = \delta - 0.08\left[\ln u^{S} - \ln u^{R}\right] + 0.06\left[\ln\left[\frac{w^{S}}{cpi^{S}}\right] - \ln\left[\frac{w^{R}}{cpi^{R}}\right]\right]$$

And since:

$$\ln\left[\frac{w^{S}}{cpi^{S}}\right] = \beta^{S} - 0.113\ln u^{S} \qquad \text{from Equation (B.1)}$$

and

$$\ln\left[\frac{w^{R}}{cpi^{R}}\right] = \beta^{R} - 0.113\ln u^{R} \qquad \text{from Equation (B.1)}$$

then, in equilibrium:

$$0 = \delta - 0.08\left[\ln u^{S} - \ln u^{R}\right] + 0.06\left[\beta^{S} - \beta^{R} + 0.113(\ln u^{S} - \ln u^{R})\right]$$

and

$$0 = \delta + [-0.08 + 0.06(0.113)]\left[\ln u^S - \ln u^R\right] + 0.06\left[\beta^S - \beta^R\right]$$

so

$$\frac{-\delta - 0.06\left[\beta^S - \beta^R\right]}{-0.07322} = \left[\ln u^S - \ln u^R\right]$$

Since this condition holds in equilibrium, then the initial (equilibrium) ratio of unemployment rates (and therefore real wages) is the same as the ratio of unemployment that exists in the long-run equilibrium, where there is also zero net migration. The ratio of unemployment rates remains constant so long as the relevant coefficients in the regional bargaining functions (Equation B.1) are the same in both regions, which is the case in the AMOSRUK model.

Since the ratio of unemployment rates remains constant in equilibrium, then:

$$\left[\ln u^S - \ln u^R\right] = K \tag{C.1}$$

where K is a constant.

Since:

$$\ln\left[\frac{w^S}{cpi^S}\right] = \beta^S - 0.113 \ln u^S \qquad \text{from Equation (B.1)}$$

and

$$\ln\left[\frac{w^R}{cpi^R}\right] = \beta^R - 0.113 \ln u^R \qquad \text{from Equation (B.1)}$$

then

$$\ln u^S = \frac{\beta^S - \ln\left[\dfrac{w^S}{cpi^S}\right]}{0.113}$$

and

$$\ln u^R = \frac{\beta^R - \ln\left[\dfrac{w^R}{cpi^R}\right]}{0.113}$$

Using Equation (C.1):

$$\frac{\beta^S - \ln\left[\dfrac{w^S}{cpi^S}\right]}{0.113} - \frac{\beta^R - \ln\left[\dfrac{w^R}{cpi^R}\right]}{0.113} = K$$

so

$$\beta^S - \beta^R + \ln\left[\frac{w^R}{cpi^R}\right] - \ln\left[\frac{w^S}{cpi^S}\right] = 0.113K$$

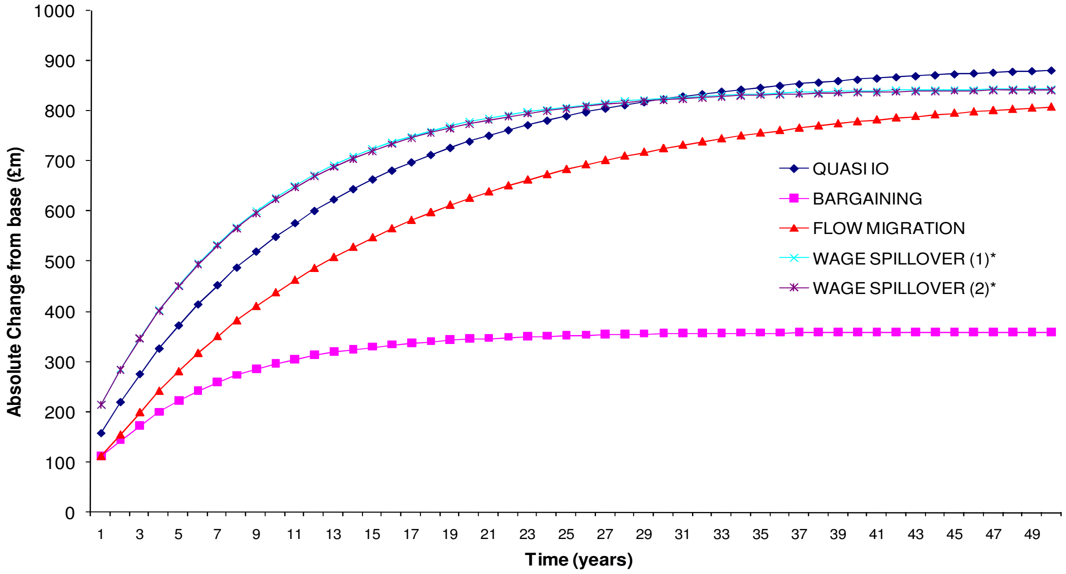
and

$$\ln\left[\frac{w^R}{cpi^R}\right] - \ln\left[\frac{w^S}{cpi^S}\right] = \beta^R - \beta^S + 0.113K \qquad \text{(C.2)}$$

Since the ratio of unemployment rates remains constant in equilibrium (Equation C.1), so too does the ratio of wage rates remain constant in equilibrium.

APPENDIX D: Chapter 3 figures

Figure D.1 Absolute change in Scottish GDP (£m)



* The wage spillover (1) and wage spillover (2) results lie virtually on top of one another.

Figure D.2 Percentage change in Scottish CPI

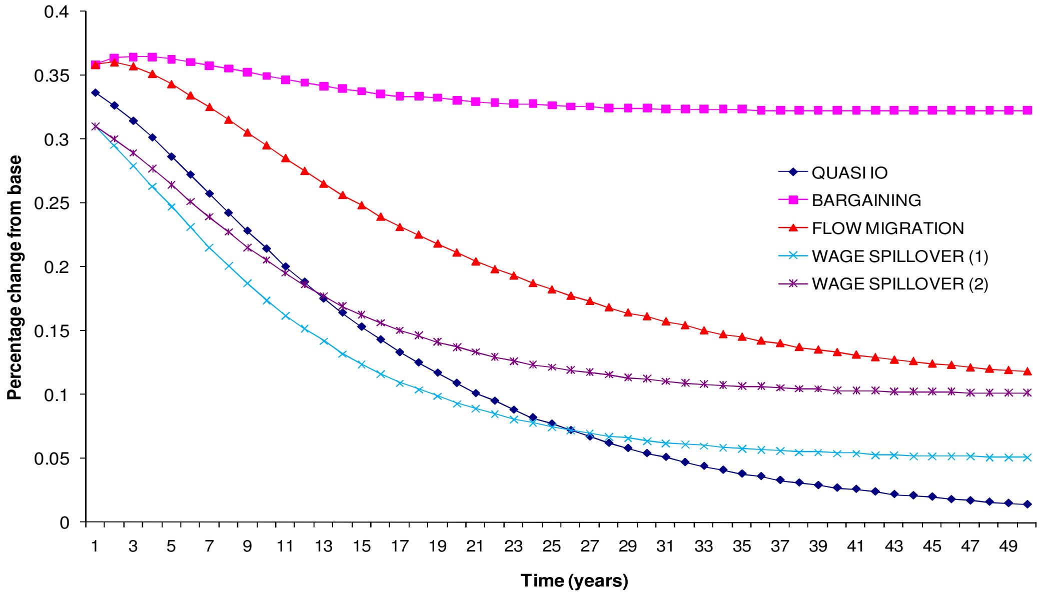
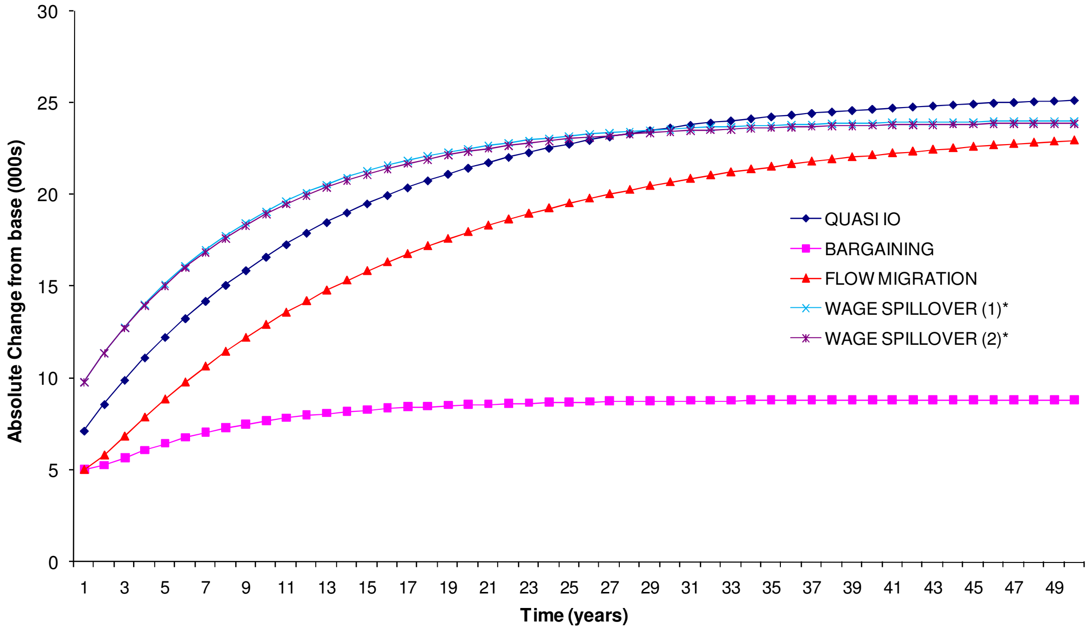


Figure D.3 Absolute change in Scottish total employment (000s)



* The wage spillover (1) and wage spillover (2) results lie virtually on top of one another.

Figure D.4 Percentage change in Scottish real wages

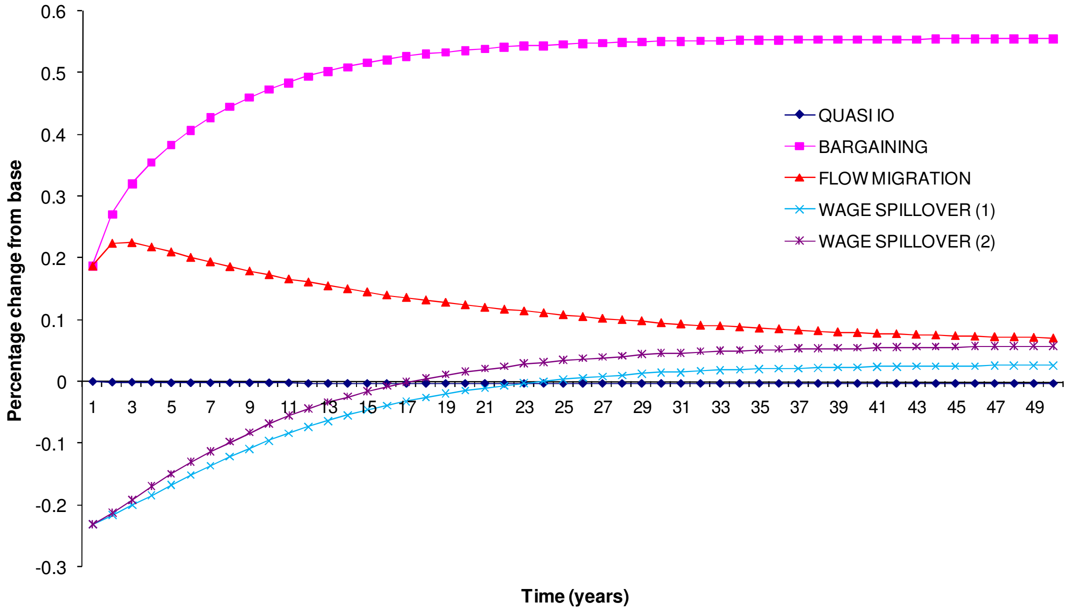


Figure D.5 Percentage change in Scottish nominal wages

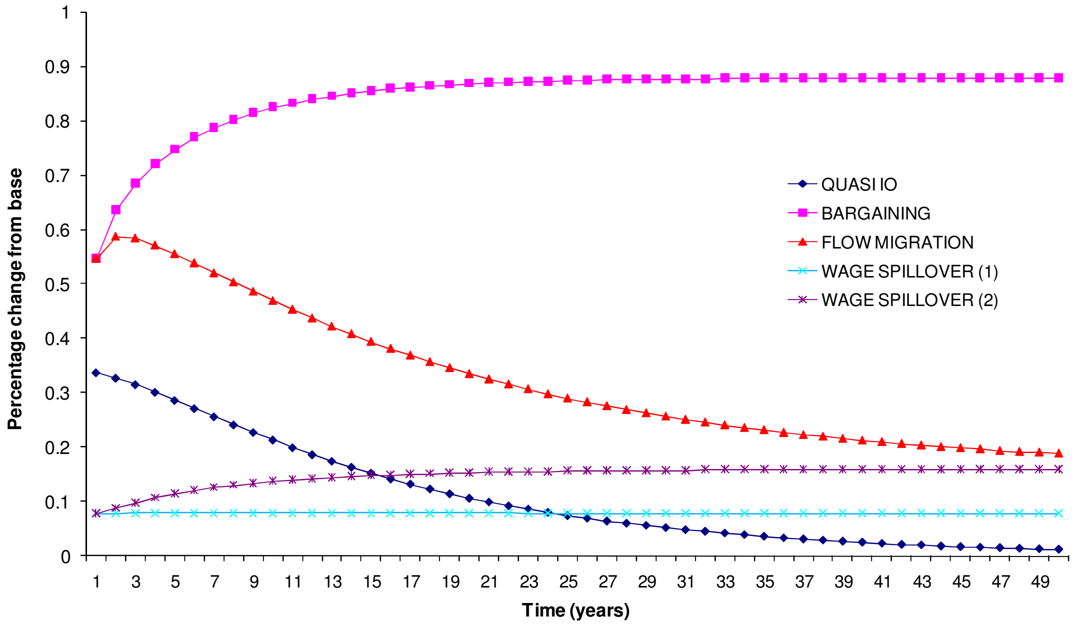


Figure D.6 Percentage change in Scottish exports to the ROW

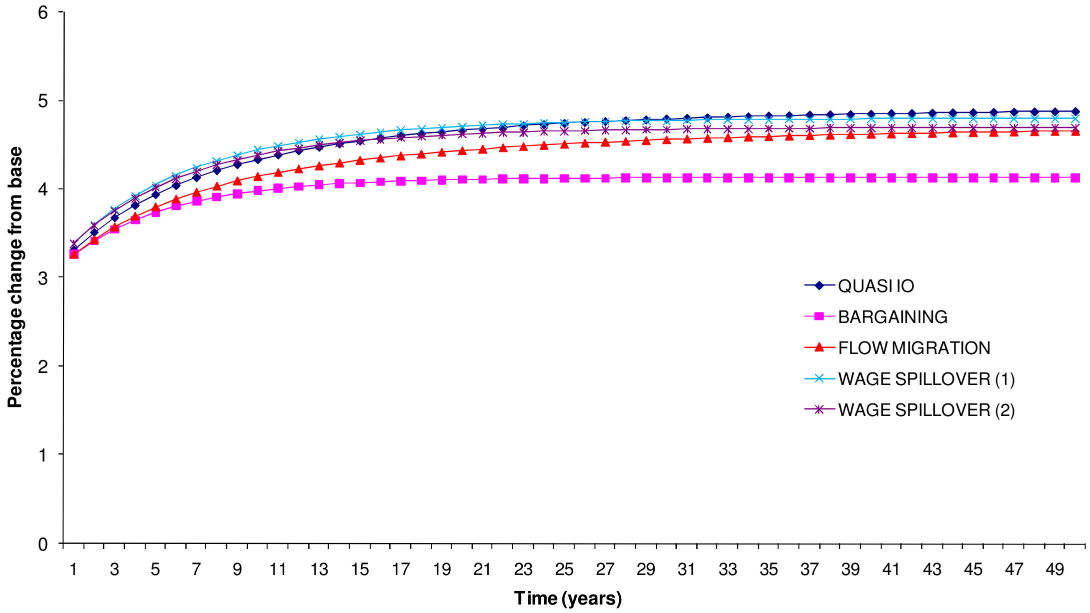


Figure D.7 Percentage change in Scottish exports to the RUK

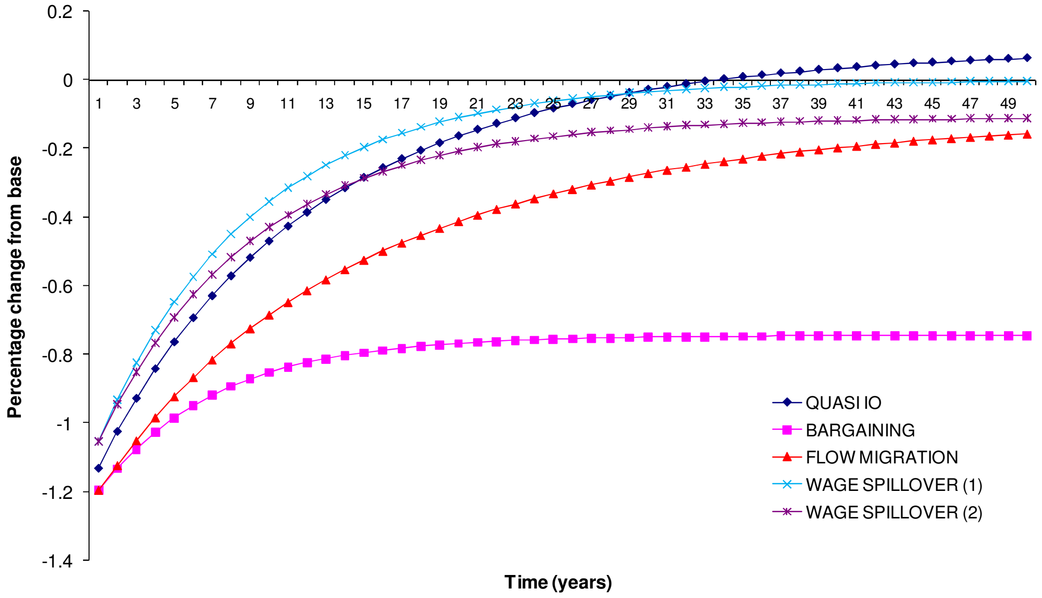


Figure D.8 Absolute change in RUK GDP (£m)

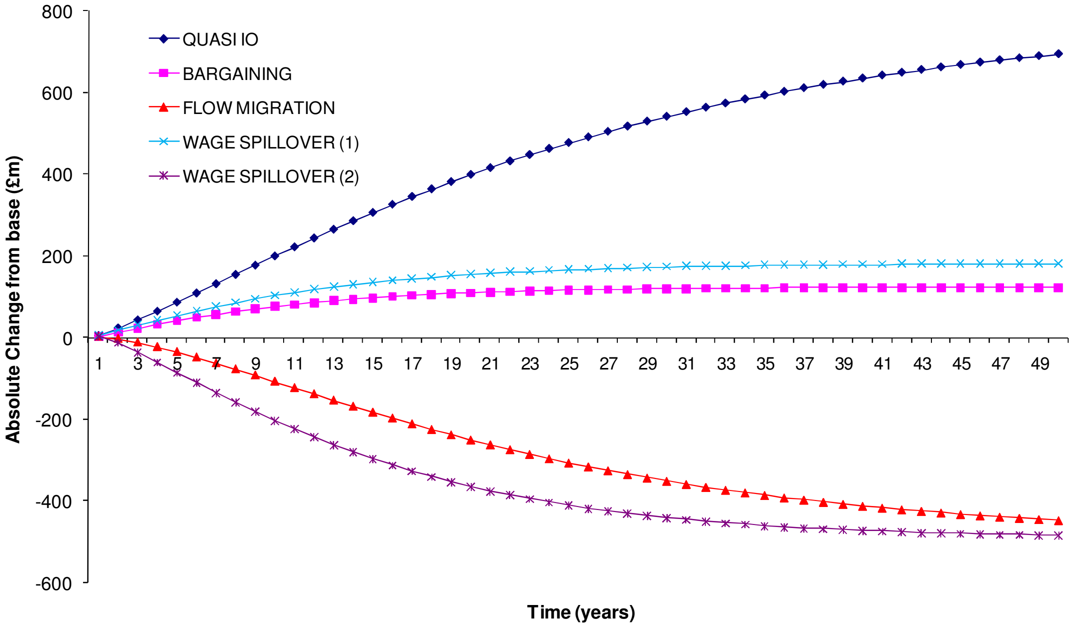


Figure D.9 Percentage change in RUK CPI

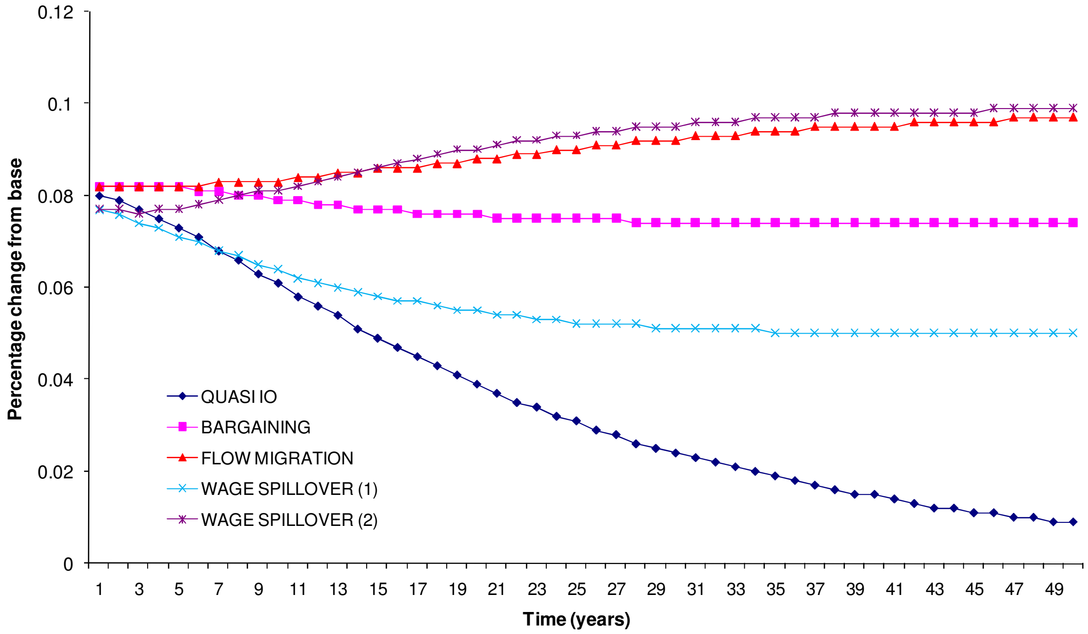


Figure D.10 Absolute change in RUK total employment (000s)

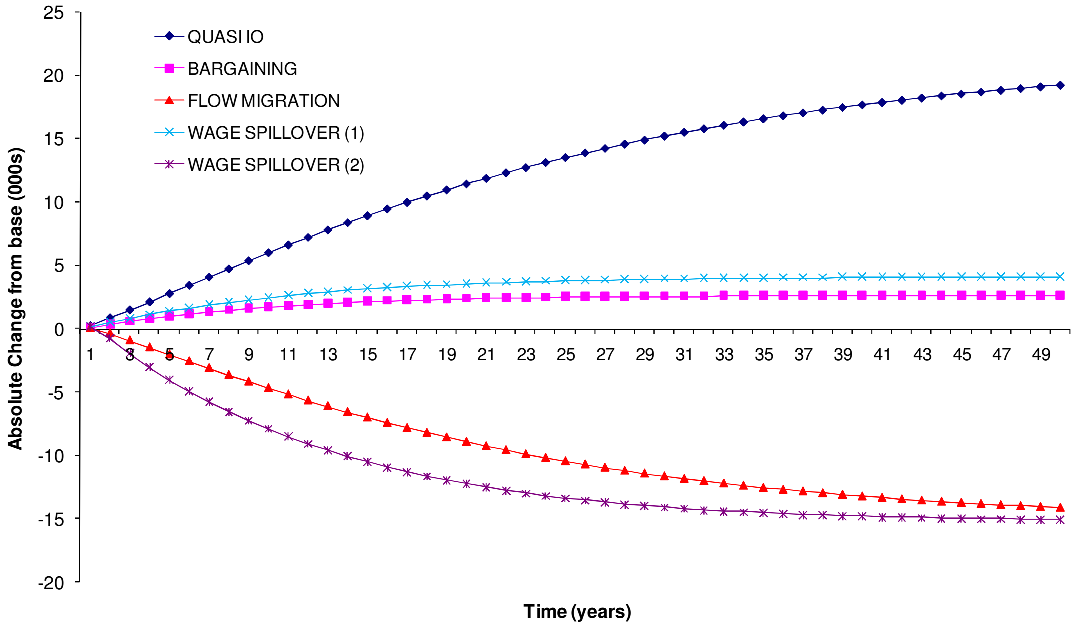


Figure D.11 Percentage change in RUK real wage

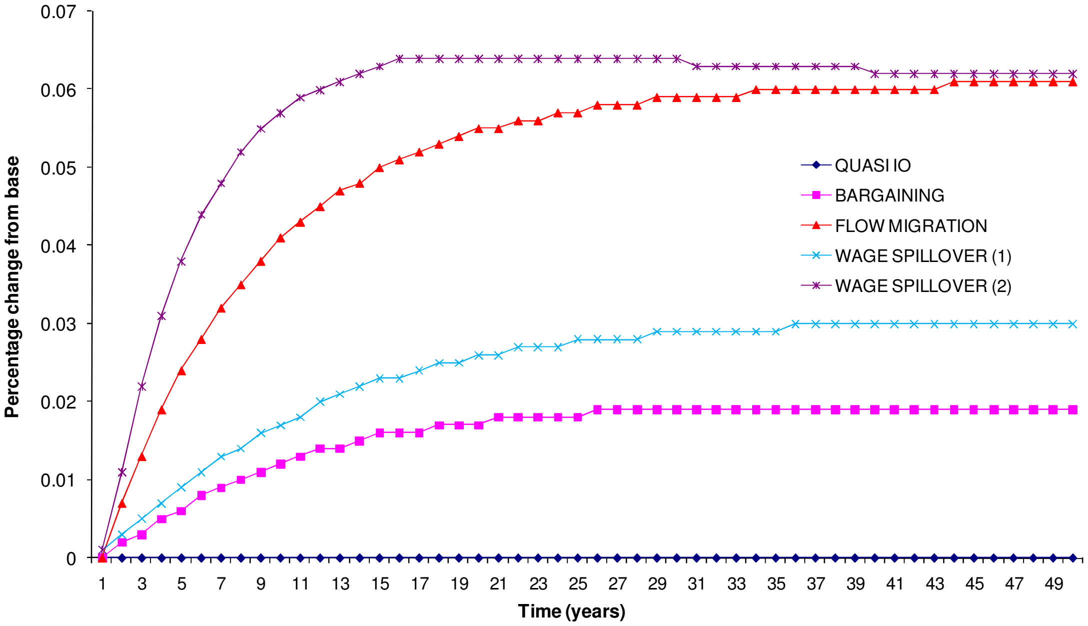


Figure D.12 Percentage change in RUK nominal wage

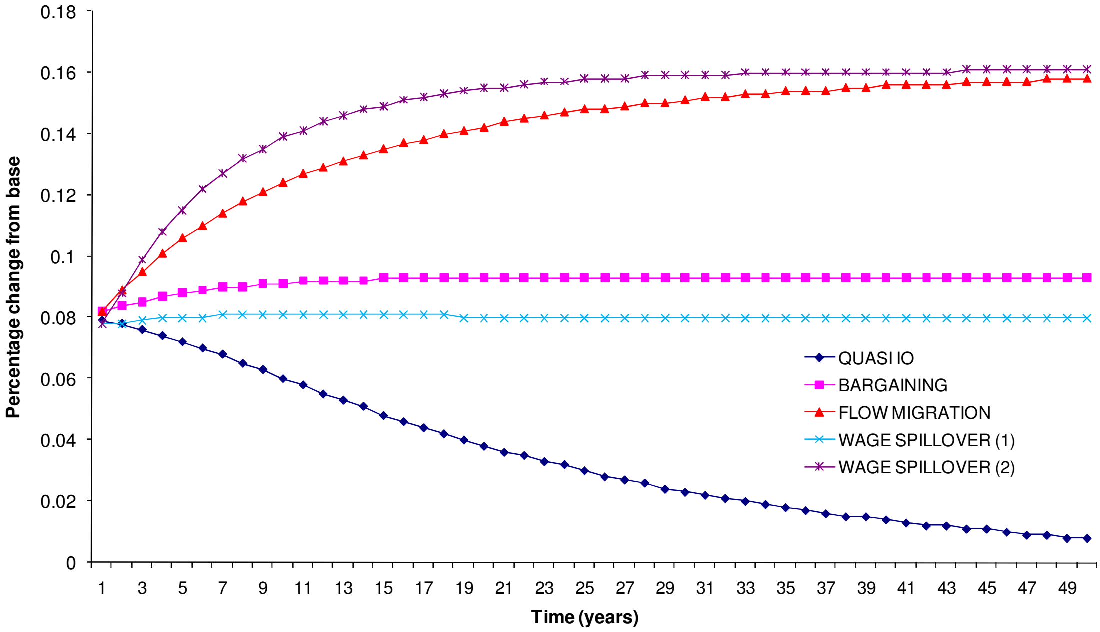


Figure D.13 Percentage change in RUK exports to the ROW

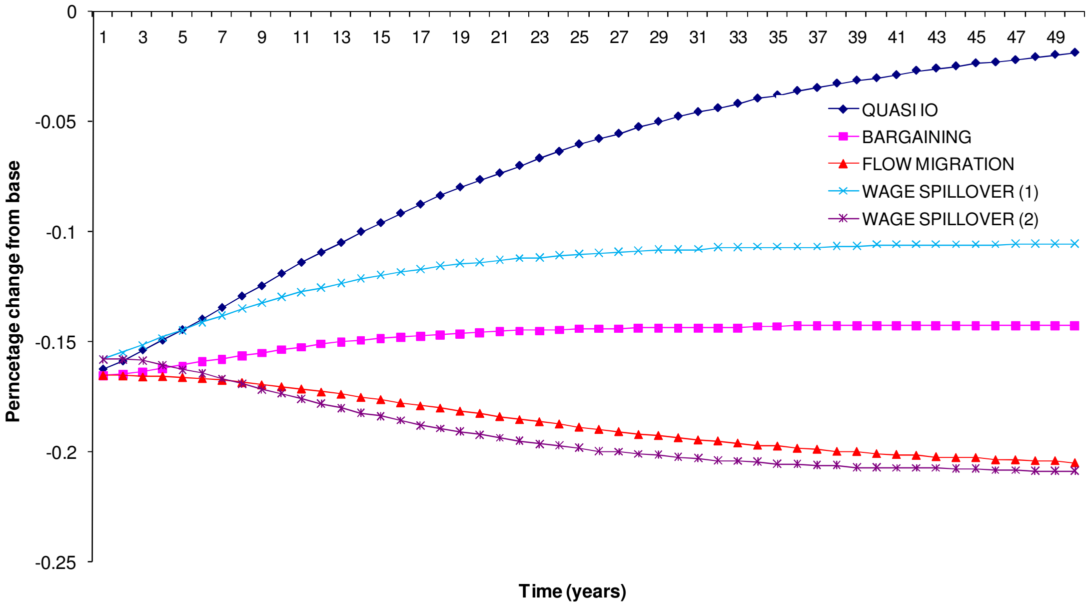


Figure D.14 Percentage change in RUK exports to Scotland

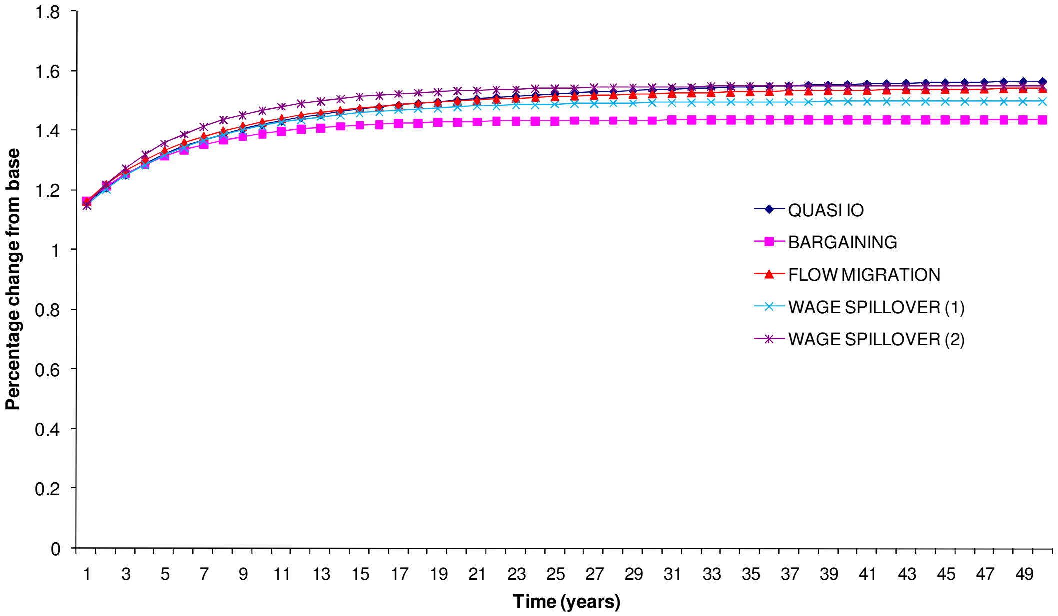


Figure D.15 Absolute change in national GDP (£m)

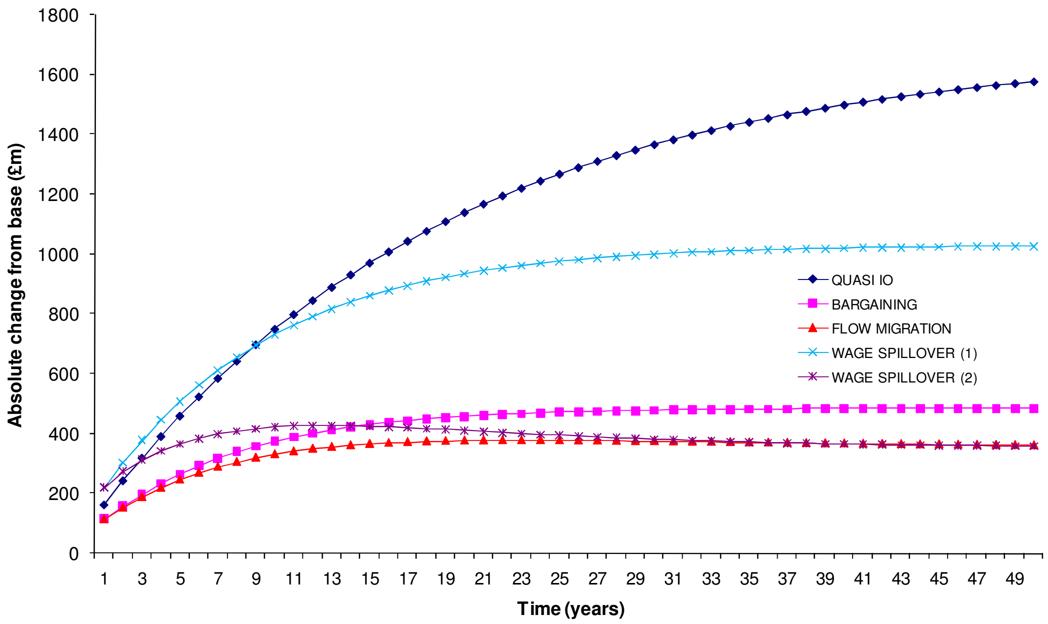
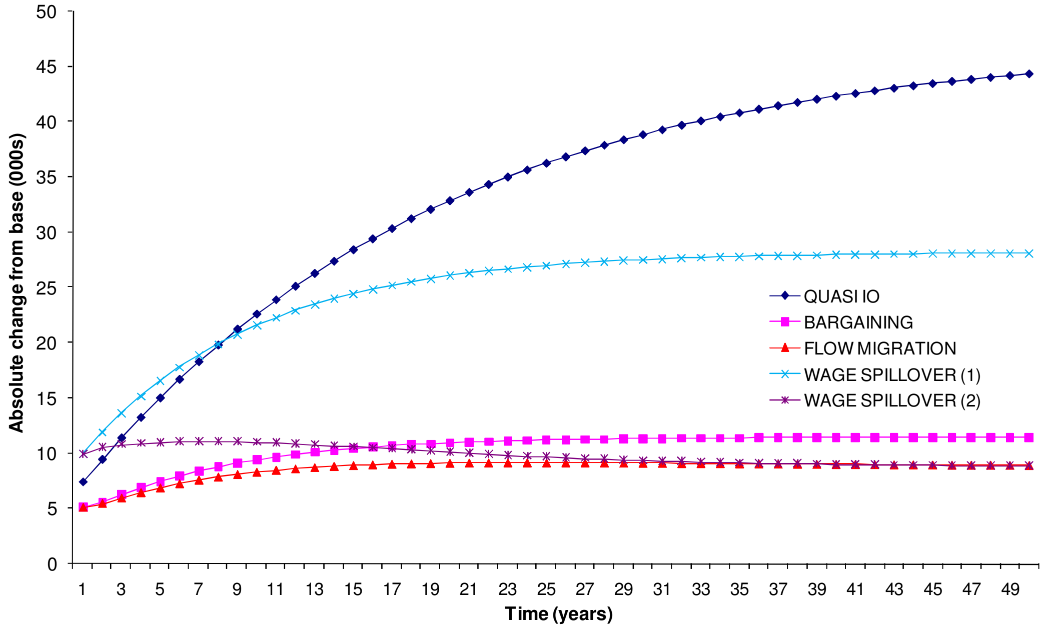


Figure D.16 Absolute change in national employment (000s)



APPENDIX E: Chapter 4 figures

Figure E.1 Percentage change in Scottish CPI

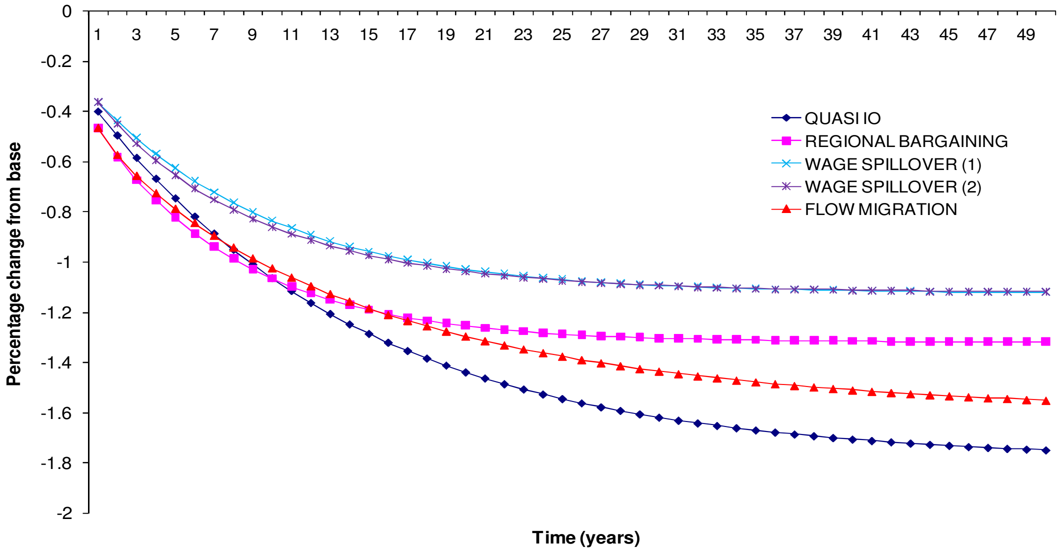


Figure E.2 Percentage change in Scottish nominal wage

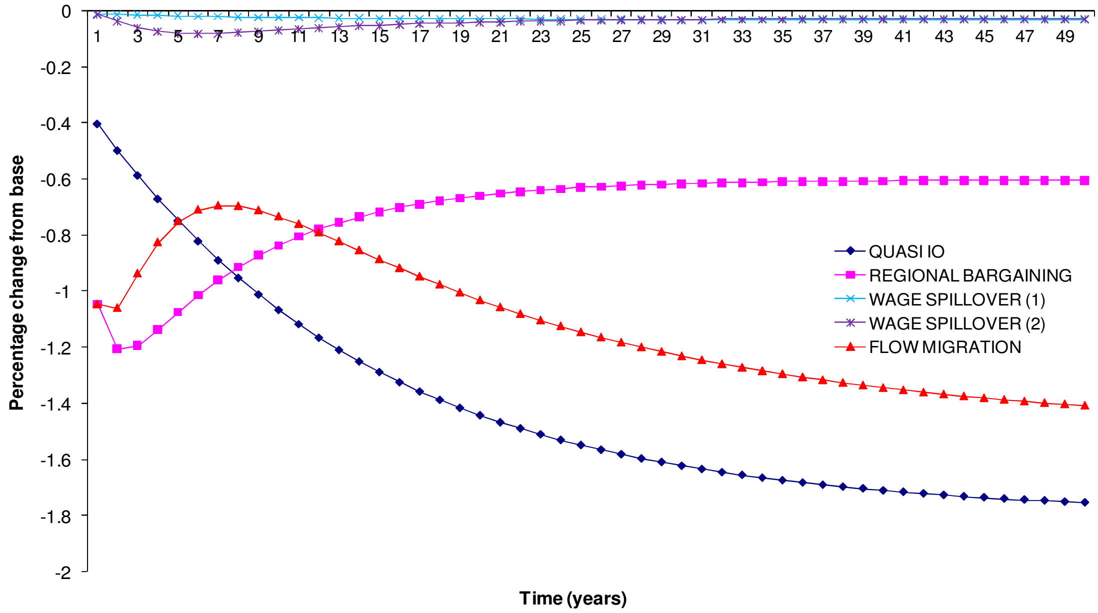


Figure E.3 Percentage change in Scottish real wage

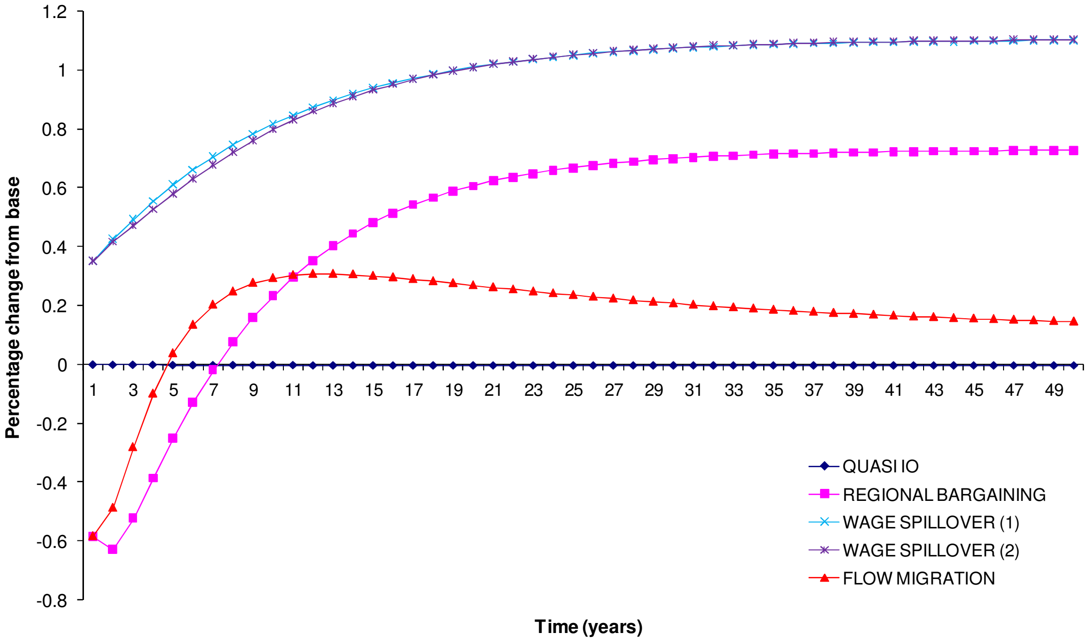


Figure E.4 Percentage change in Scottish exports to the RUK

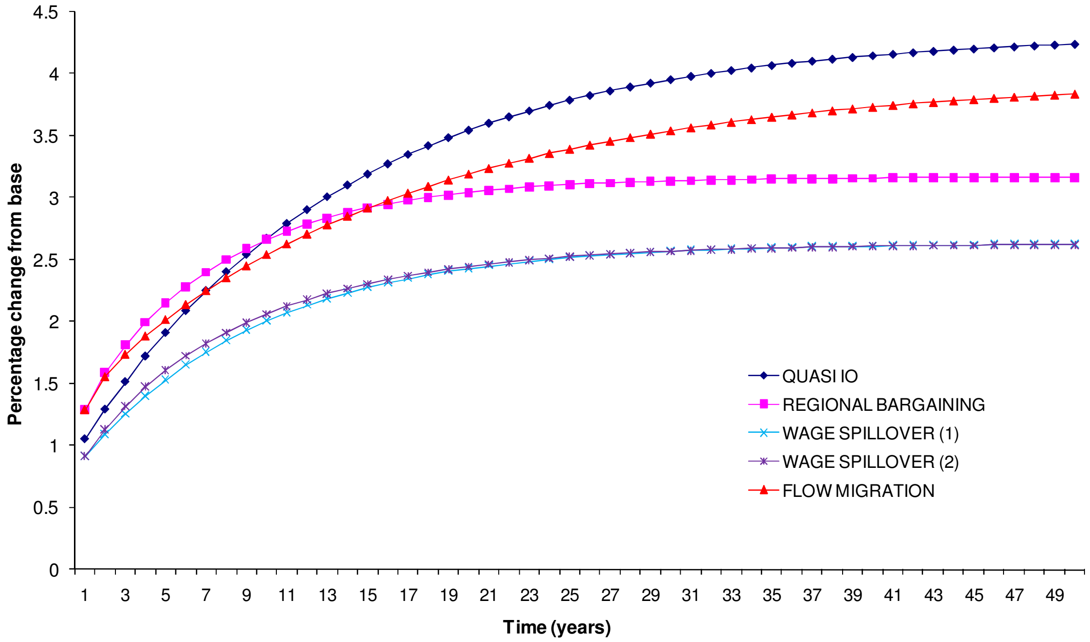


Figure E.5 Percentage change in Scottish exports to the ROW

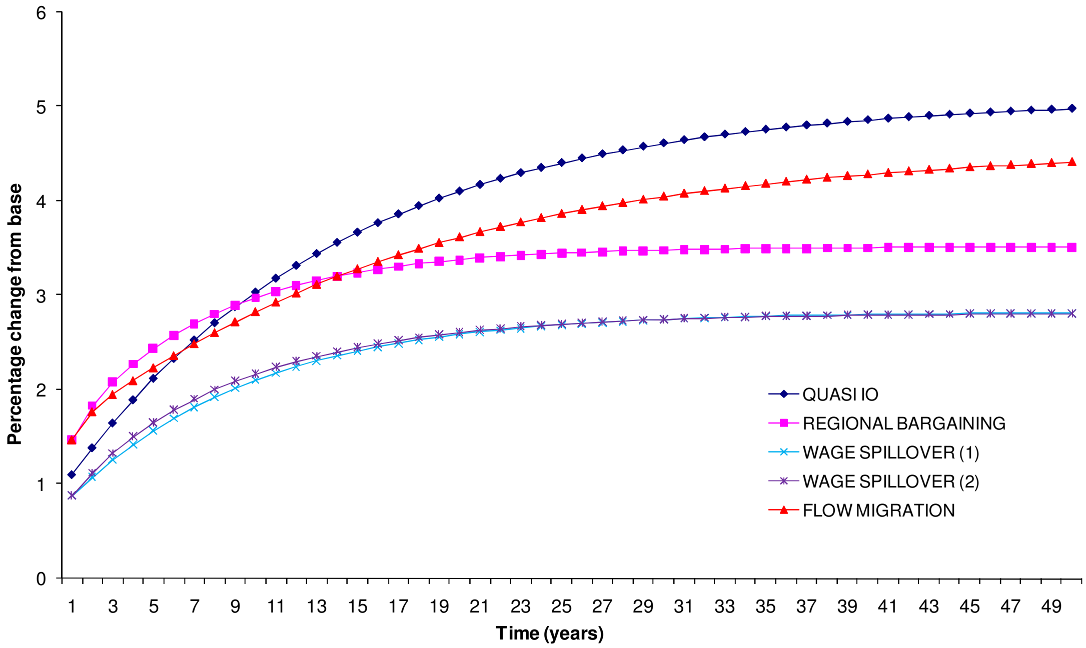
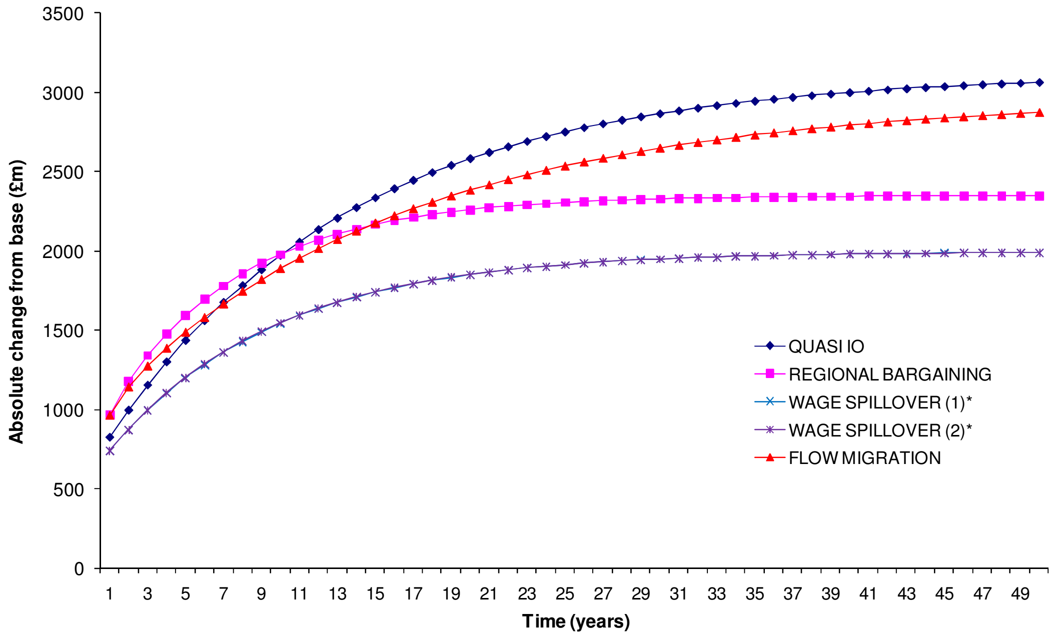
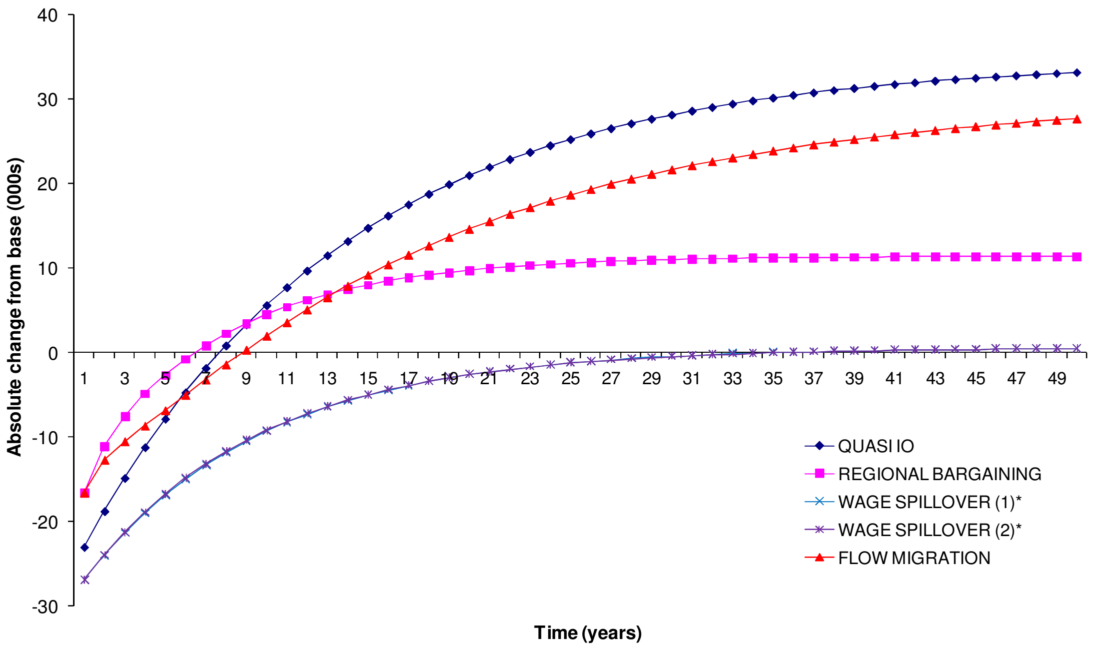


Figure E.6 Absolute change in Scottish GDP (£m)



* The wage spillover (1) and wage spillover (2) results lie virtually on top of one another.

Figure E.7 Absolute change in Scottish total employment (000s)



* The wage spillover (1) and wage spillover (2) results lie virtually on top of one another.

Figure E.8 Percentage change in RUK CPI

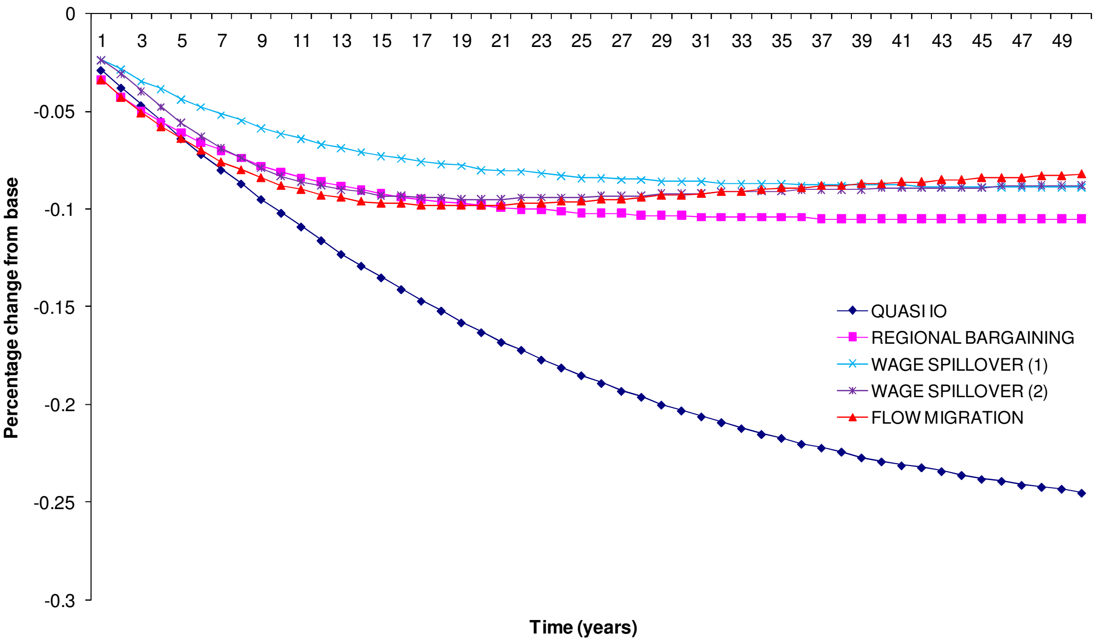


Figure E.9 Percentage change in RUK nominal wage

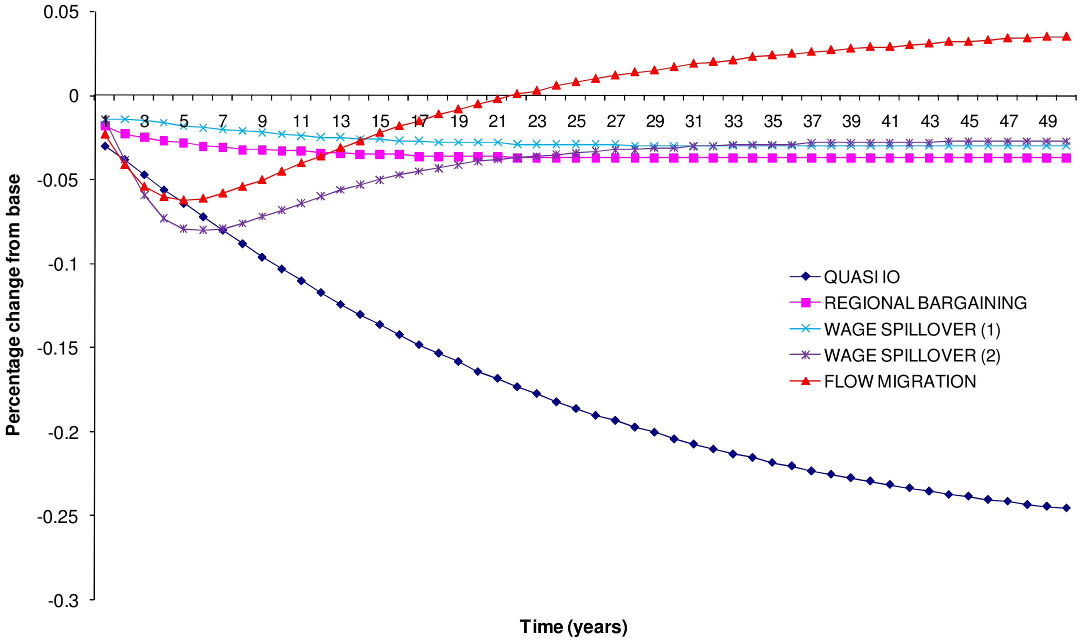


Figure E.10 Percentage change in RUK real wage

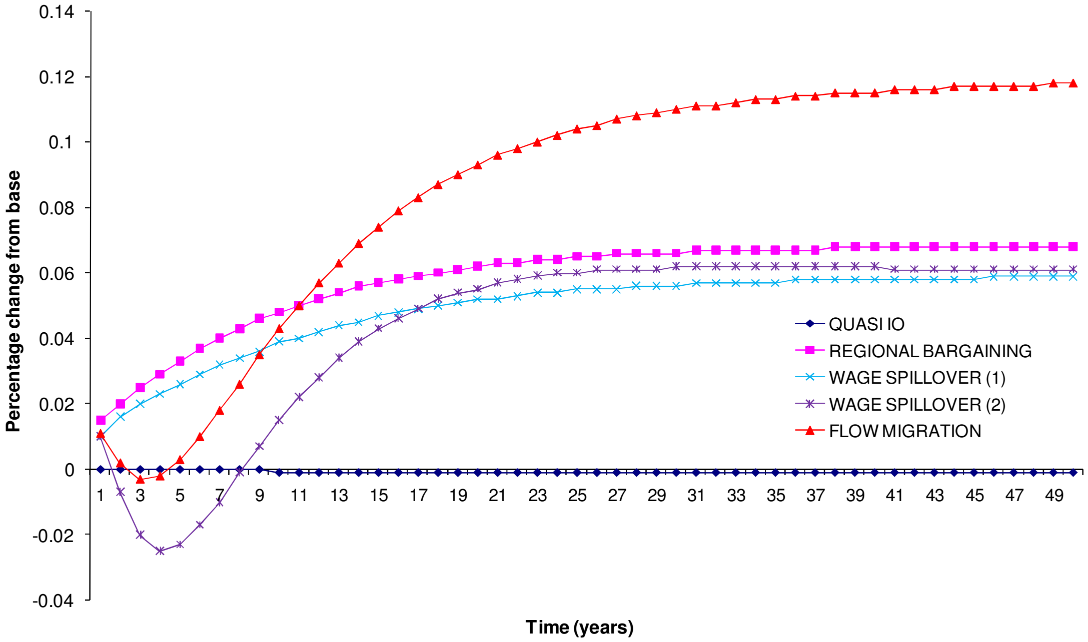


Figure E.11 Percentage change in RUK exports to Scotland

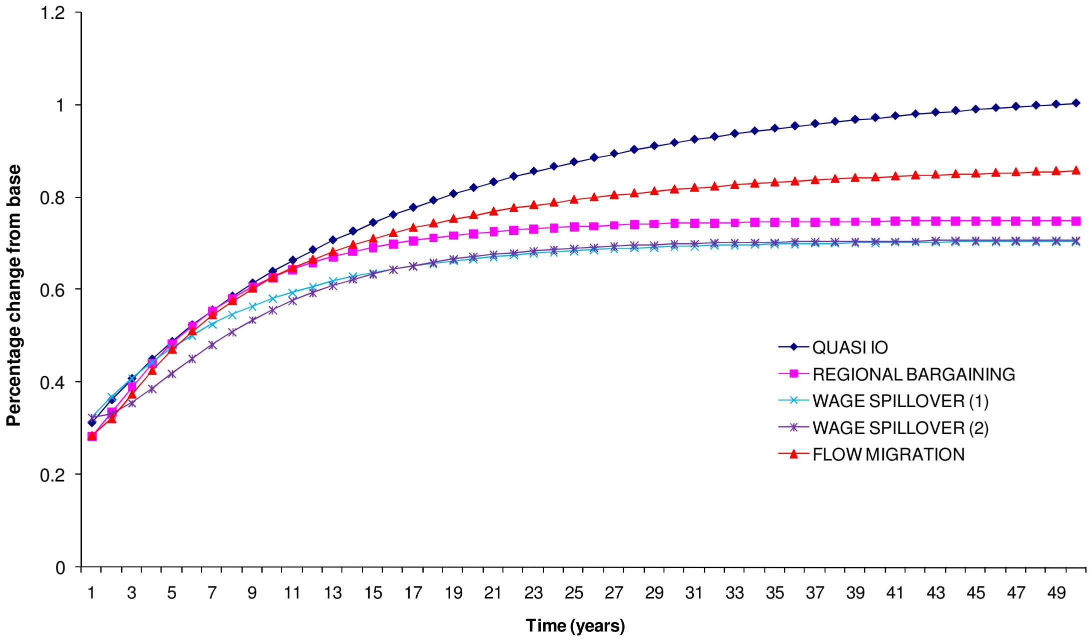


Figure E.12 Percentage change in RUK exports to the ROW

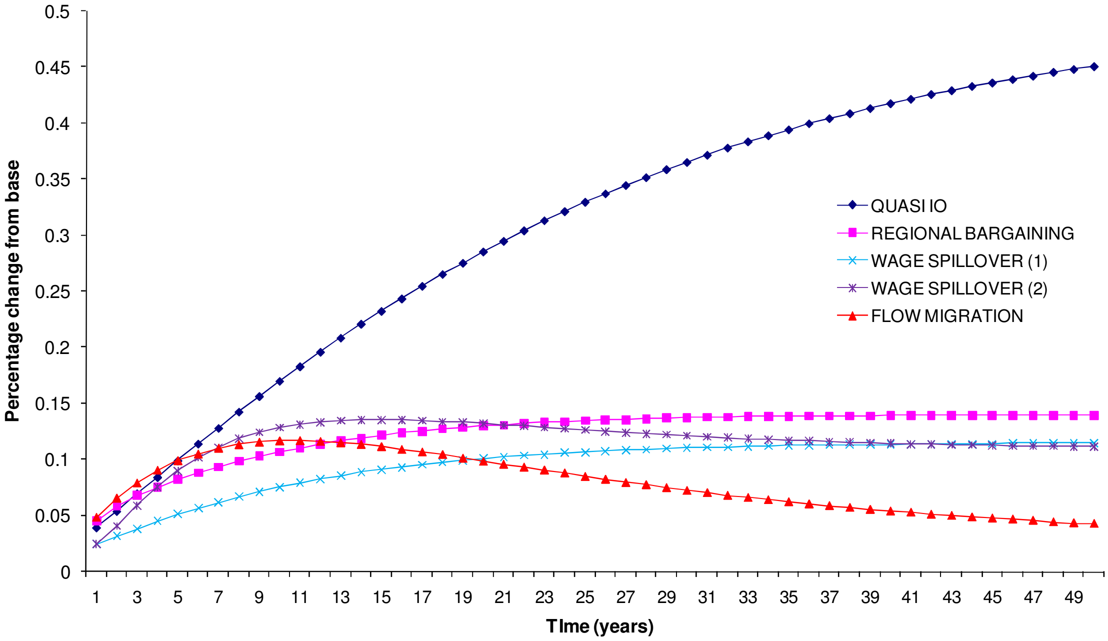


Figure E.13 Absolute change in RUK GDP (£m)

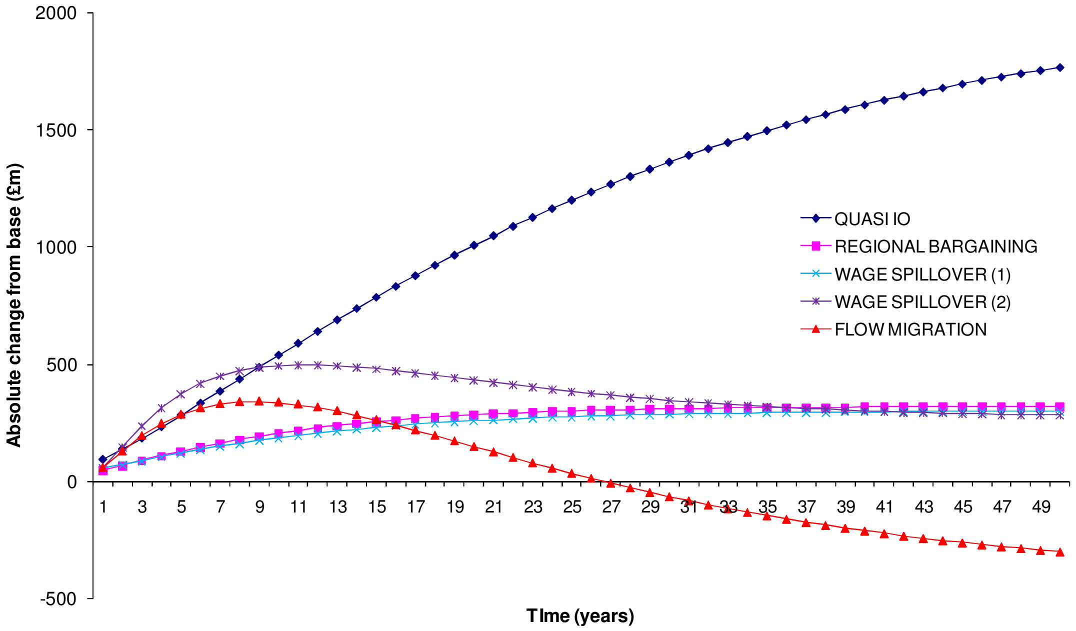


Figure E.14 Absolute change in RUK total employment (000s)

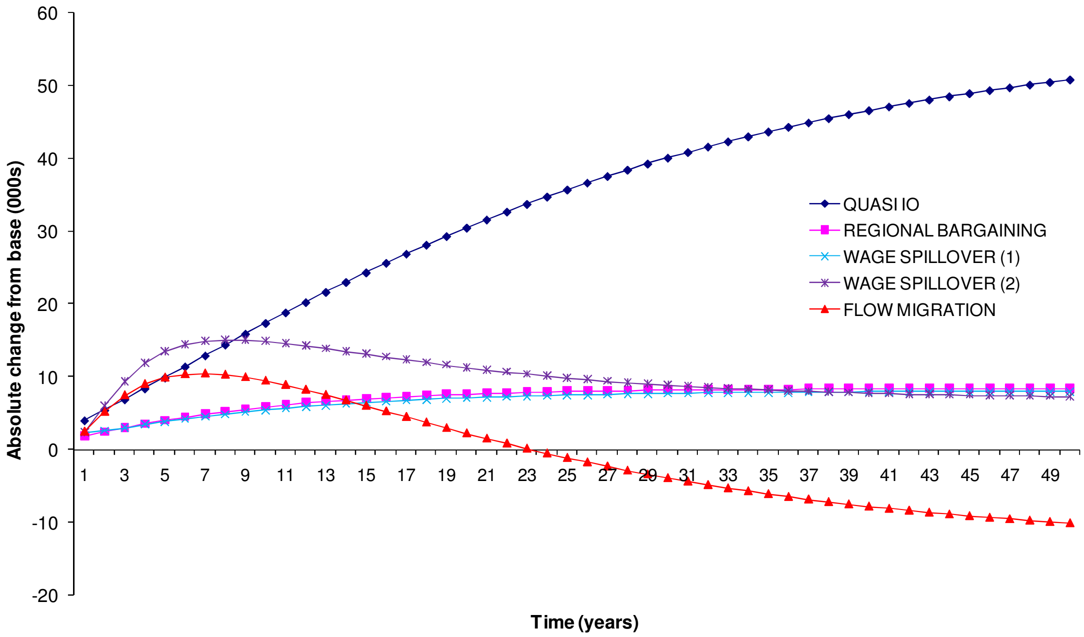


Figure E.15 Absolute change in national GDP (£m)

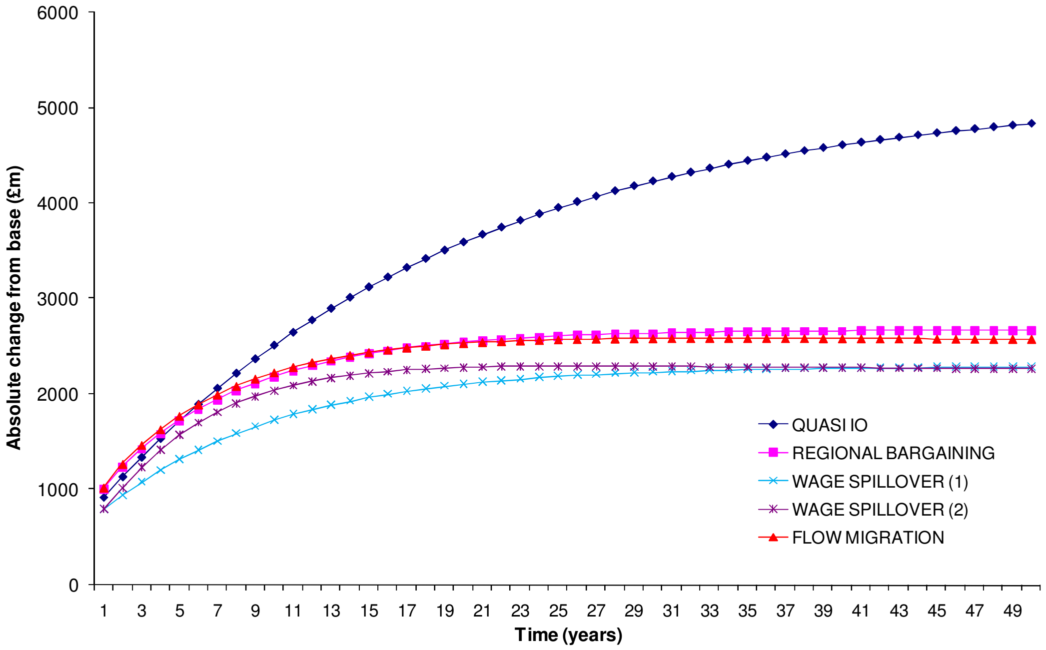
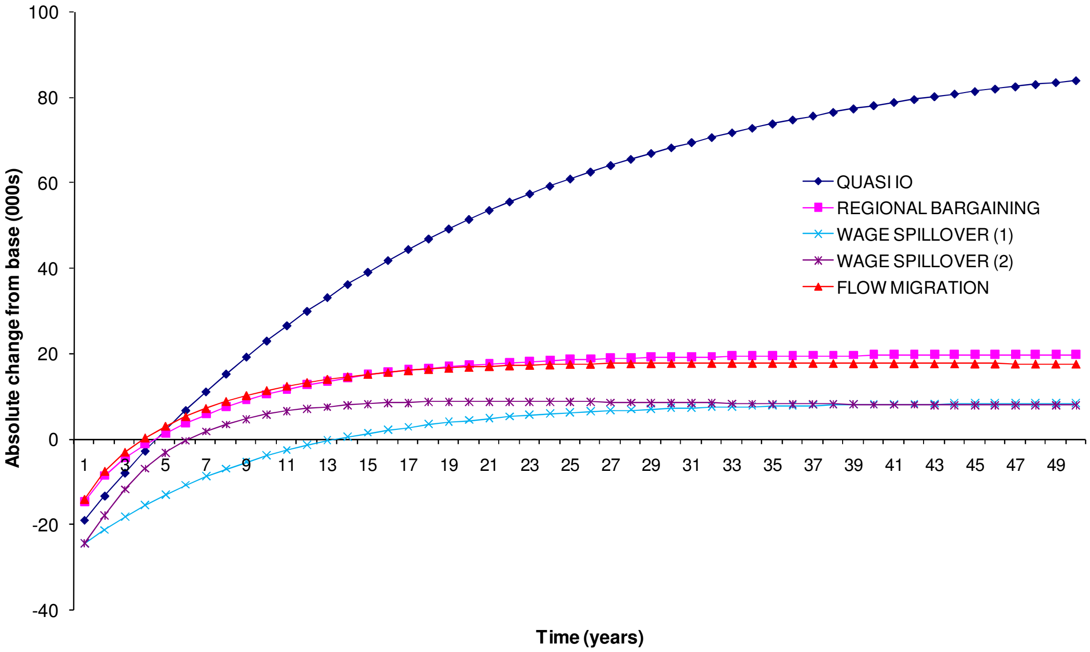


Figure E.16 Absolute change in national employment (000s)



APPENDIX F: Chapter 5 tables

Table F.1 The CO_2 trade balance between Scotland and the RUK (tonnes, millions): Type II I-O results

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	11.3	4.3	14.6	5.7	5.1	8.0	48.9
RUK	8.1	6.3	10.8	144.5	117.9	228.0	515.5
Total UK emissions supported by	19.3	10.6	25.4	150.1	122.9	236.0	564.4
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							18.8
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							25.2
Scotland's CO_2 trade balance							-6.4

Table F.2 The sectoral breakdown of the Scotland-RUK interregional system

Scottish/RUK AMOSRUK sector		IOC
1	Primary, manufacturing and construction	1-84, 88
2	Electricity, gas and water supply	85-87
3	Services	89-123

Table F.3 Percentage change in key variables following a 10% increase in ROW demand for the RUK primary, manufacturing and construction sector

	Output		Value-added		Employment		Direct CO2 emissions	
	Base (£million)	% change	Base (£million)	% change	Base (FTE,	% change	Base (tonnes,	% change
Scotland:								
PRIMARY, MFR and CONSTRUCTION	52471	0.99%	17134	0.99%	483	0.99%	12.4	0.99%
ELEC, GAS & WATER SUPPLY	5047	1.52%	1508	1.52%	14	1.52%	16.3	1.52%
SERVICES	83723	0.81%	43982	0.81%	1334	0.81%	9.6	0.81%
HOUSEHOLDS	40415	0.87%					10.7	0.87%
Total Scotland			62624	0.87%	1832	0.86%	48.9	1.10%
RUK:								
PRIMARY, MFR and CONSTRUCTION	506584	4.46%	198046	4.46%	5581	4.46%	145.4	4.46%
ELEC, GAS & WATER SUPPLY	42067	2.91%	12896	2.91%	142	2.91%	128.9	2.91%
SERVICES	1031837	1.90%	504567	1.90%	16754	1.90%	109.0	1.90%
HOUSEHOLDS	453771.00	2.63%					132.3	2.63%
Total RUK			715508	2.63%	22477	2.54%	515.5	3.06%
Total	2215914	2.60%	778132	2.49%	24309	2.41%	564.4	2.89%

Table F.4 The post-shock CO_2 trade balance between Scotland and the RUK (tonnes, millions): Type II I-O results

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	11.3	4.3	14.6	5.7	5.1	8.6	49.4
RUK	8.1	6.3	10.8	144.5	117.9	243.8	531.3
Total UK emissions supported by	19.3	10.6	25.4	150.1	122.9	252.3	580.8
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							19.3
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							25.2
Scotland's CO_2 trade balance							-5.9

Table F.5 The post-shock CO_2 trade balance between Scotland and the RUK: Type II I-O results (percentage change from base)

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	0.00%	0.00%	0.00%	0.00%	0.00%	6.72%	1.10%
RUK	0.00%	0.00%	0.00%	0.00%	0.00%	6.92%	3.06%
Total UK emissions supported by	0.00%	0.00%	0.00%	0.00%	0.00%	6.91%	2.89%
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							2.88%
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							0.00%
Scotland's CO_2 trade balance							-8.41%

Table F.6 Alternative visions of the labour market

	Population	Regional Wage Setting	
		Scotland	RUK
Quasi IO	Fixed at the regional level	Fixed real wage	Fixed real wage
Regional Bargaining	Fixed at the regional level	Bargaining	Bargaining
Flow Migration	Fixed at the national level	Bargaining	Bargaining

Table F.7 The post-shock CO_2 trade balance between Scotland and the RUK: Quasi I-O CGE results (tonnes, millions)

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	11.3	4.3	14.3	5.6	5.1	8.3	48.9
RUK	7.9	6.1	10.4	143.4	116.8	233.5	518.2
Total UK emissions supported by	19.2	10.4	24.7	149.0	121.9	241.8	567.0
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							19.0
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							24.5
Scotland's CO_2 trade balance							-5.5

Table F.8 The post-shock trade balance between Scotland and the RUK: Quasi I-O results, period 1 (percentage change from base)

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	-0.09%	0.05%	-1.84%	-0.34%	0.23%	3.04%	-0.08%
RUK	-1.60%	-2.37%	-3.92%	-0.78%	-0.93%	2.43%	0.51%
Total UK emissions supported by	-0.72%	-1.39%	-2.72%	-0.76%	-0.88%	2.45%	0.46%
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							1.26%
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							-2.79%
Scotland's CO_2 trade balance							-14.63%

Table F.9 The post-shock CO_2 trade balance between Scotland and the RUK: Quasi I-O results (percentage change from base)

	Period/year after demand disturbance introduced:							
	1	5	10	15	20	30	50	75
Environmental trade balance:								
Pollution generated in Scotland and supported by RUK final demand	1.26%	1.58%	1.84%	2.03%	2.21%	2.62%	2.94%	3.06%
Pollution generated in RUK and supported by Scottish final demand	-2.79%	-2.34%	-1.84%	-1.48%	-1.20%	-0.70%	-0.33%	-0.23%
Scotland's CO2 trade balance	-14.63%	-13.78%	-12.59%	-11.75%	-11.16%	-10.41%	-9.90%	-9.83%

Table F.10 The post shock CO_2 trade balance between Scotland and the RUK: Quasi I-O CGE results, period 75 (percentage change from base)

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	-0.06%	0.93%	-0.10%	-0.60%	2.34%	6.09%	1.21%
RUK	-0.47%	0.55%	-0.50%	-0.50%	2.38%	6.43%	3.24%
Total UK emissions supported by	-0.23%	0.70%	-0.27%	-0.50%	2.38%	6.42%	3.06%
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							3.06%
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							-0.23%
Scotland's CO_2 trade balance							-9.83%

Table F.11 The post-shock trade balance between Scotland and the RUK: Bargaining CGE results, period 75 (percentage change from base)

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	0.01%	0.01%	-1.64%	-0.03%	0.27%	3.91%	0.18%
RUK	-1.52%	-1.52%	-3.18%	-0.77%	-0.51%	3.48%	1.10%
Total UK emissions supported by	-0.63%	-0.90%	-2.30%	-0.74%	-0.48%	3.50%	1.02%
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							1.74%
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							-2.23%
Scotland's CO_2 trade balance							-13.84%

Table F.12 The post-shock CO_2 trade between Scotland and the RUK: Flow Migration CGE results, period 75 (percentage change from base)

	Pollution supported by:						
	Scottish Govt	Scottish Capital	Scot-ROW	RUK Govt	RUK Capital	RUK-ROW	Total regional emissions of CO_2
Pollution generated in:							
Scotland	-0.31%	-1.45%	-2.70%	-1.20%	-0.79%	2.76%	-0.77%
RUK	-0.90%	-2.06%	-3.54%	-0.74%	-0.42%	3.54%	1.15%
Total UK emissions supported by	-0.56%	-1.81%	-3.06%	-0.76%	-0.44%	3.52%	0.98%
Environmental trade balance:							
Total CO_2 pollution generated in Scotland that is supported by RUK final demands							0.61%
Total CO_2 pollution generated in RUK that is supported by Scottish final demands							-2.32%
Scotland's CO_2 trade balance							-10.89%

Table F.13 The post-shock CO_2 trade balance between Scotland and the RUK: All labour market scenario CGE results (percentage change from base)

	Period/year after demand disturbance introduced:							
	1	5	10	15	20	30	50	75
Scotland's CO_2 trade balance:								
Quasi IO	-14.63%	-13.78%	-12.59%	-11.75%	-11.16%	-10.41%	-9.90%	-9.83%
Bargaining	-15.00%	-14.86%	-14.42%	-14.06%	-13.93%	-13.84%	-13.84%	-13.84%
Flow Migration	-15.00%	-14.50%	-13.59%	-12.78%	-12.31%	-11.58%	-11.03%	-10.89%

APPENDIX G: Chapter 5 figures

Figure G.1 Percentage change in RUK GDP

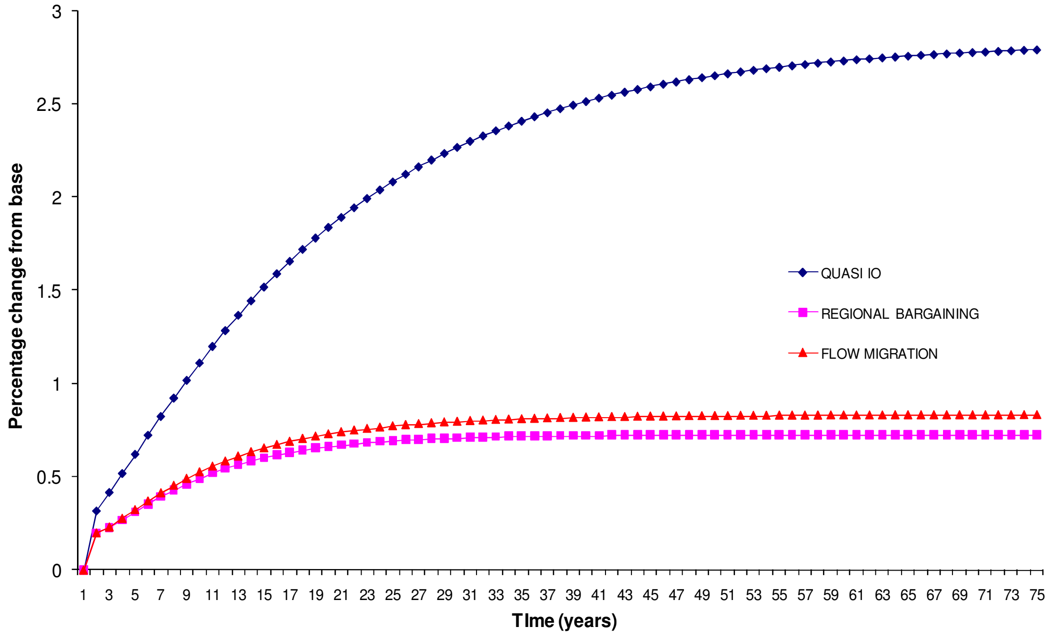


Figure G.2 Percentage change in RUK CPI

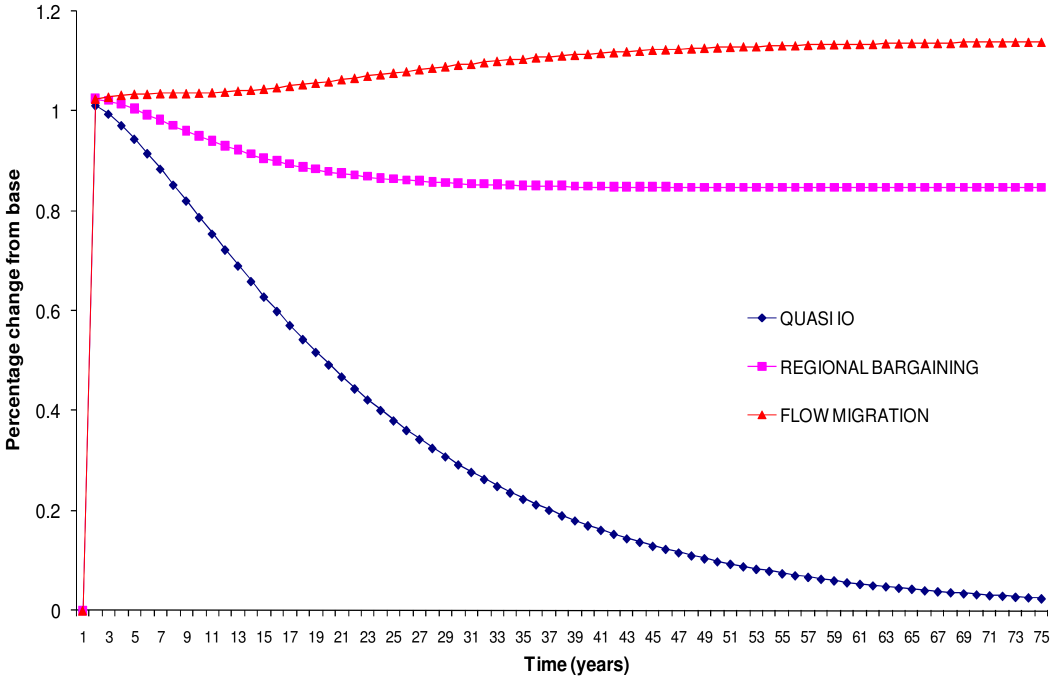


Figure G.3 Percentage change in RUK nominal wage

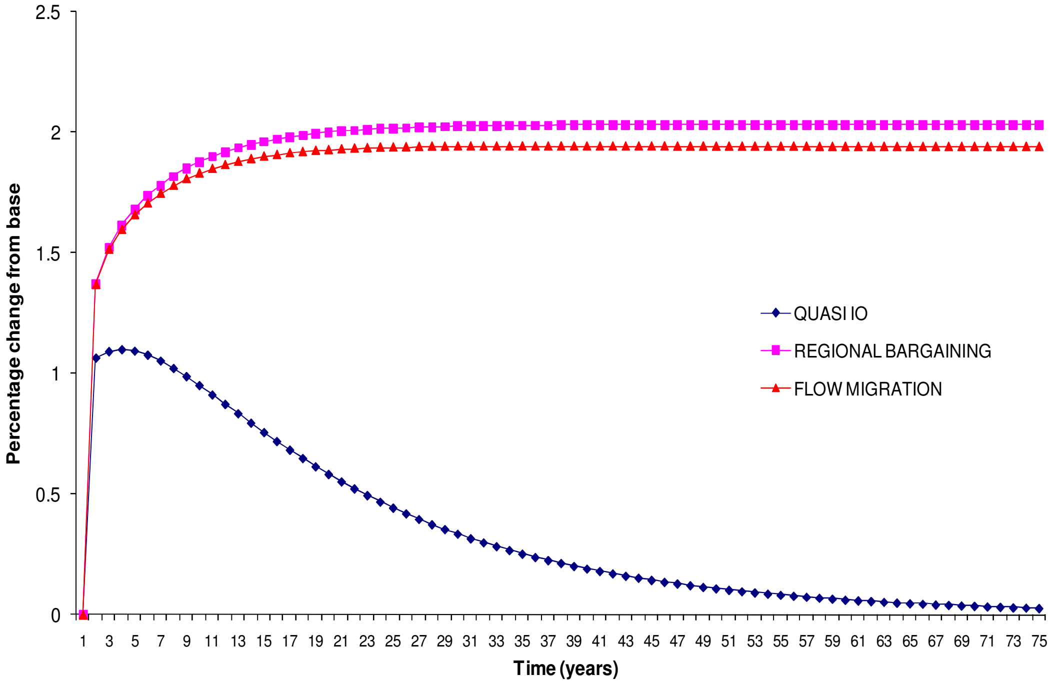


Figure G.4 Percentage change in RUK total employment

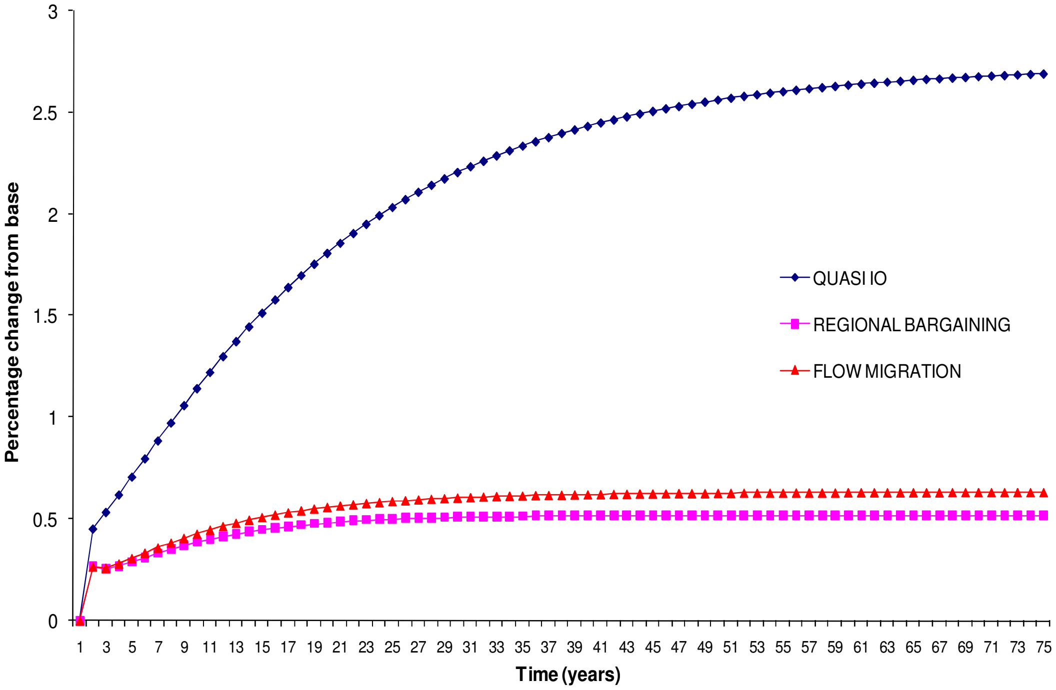


Figure G.5 Percentage change in RUK real wage

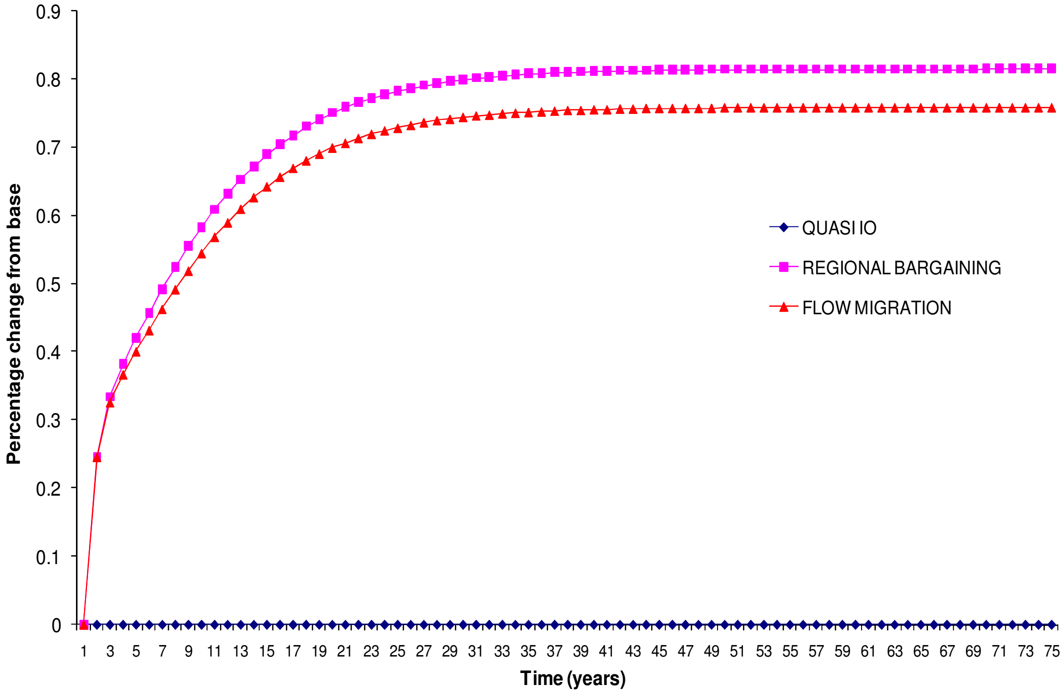


Figure G.6 Percentage change in RUK exports to Scotland

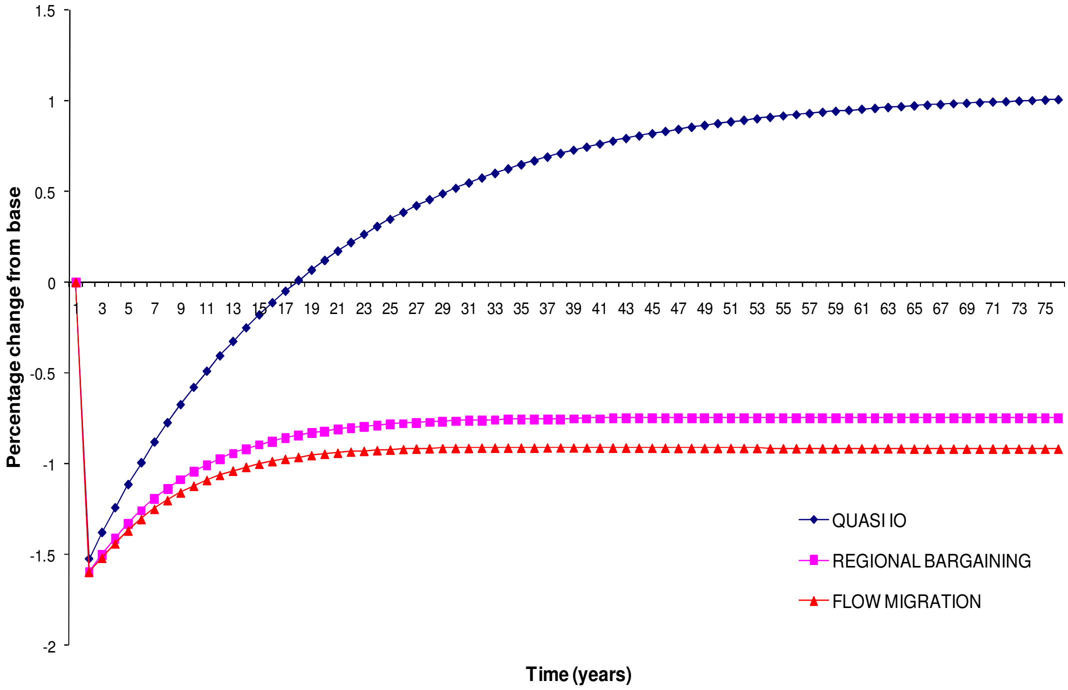


Figure G.7 Percentage change in RUK exports to the ROW

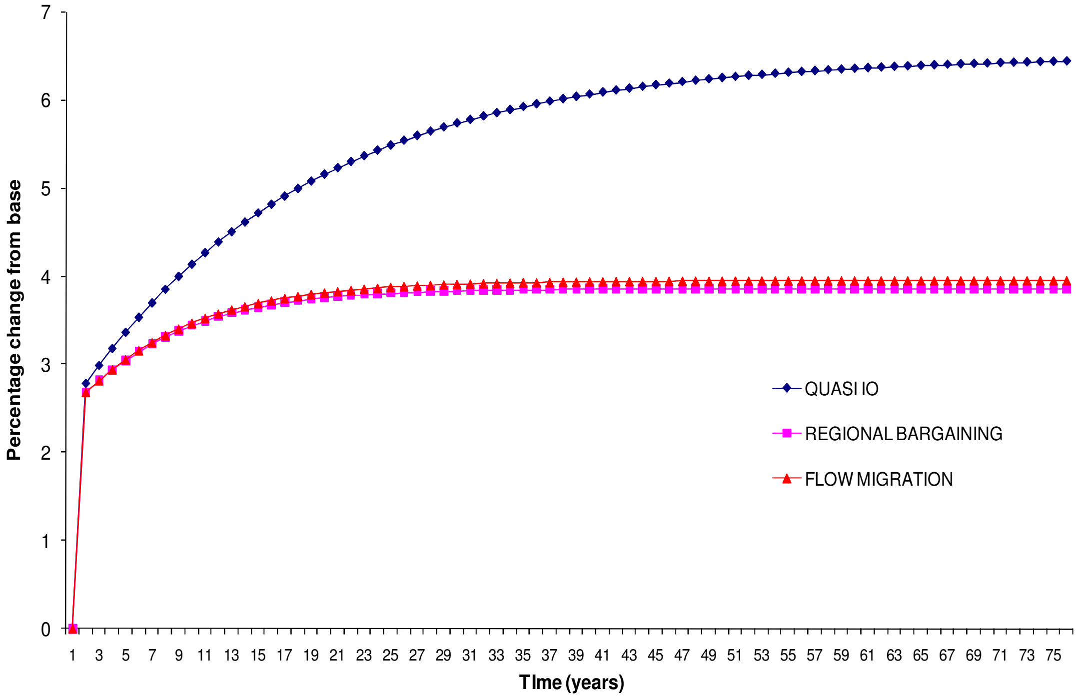


Figure G.8 Percentage change in Scottish GDP

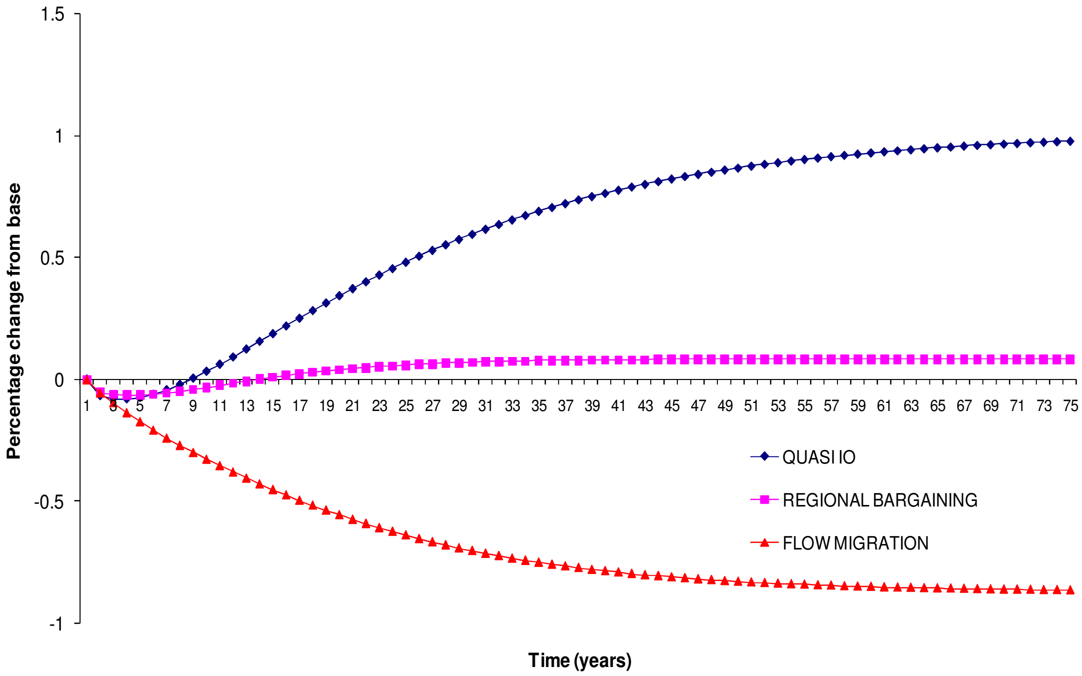


Figure G.9 Percentage change in Scottish CPI

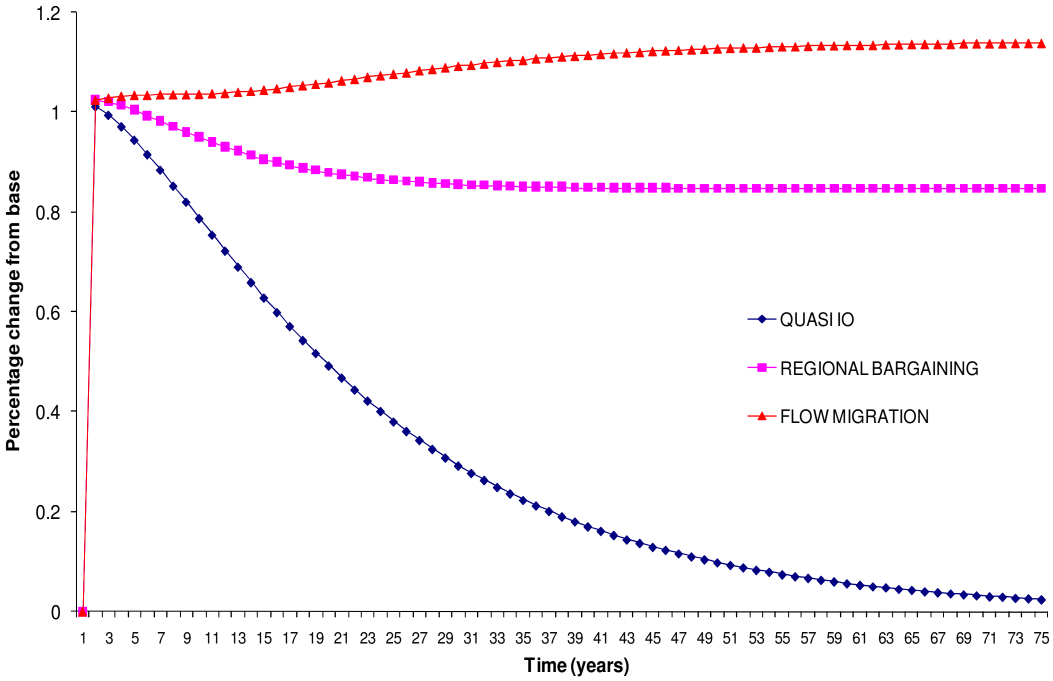


Figure G.10 Percentage change in Scottish nominal wage

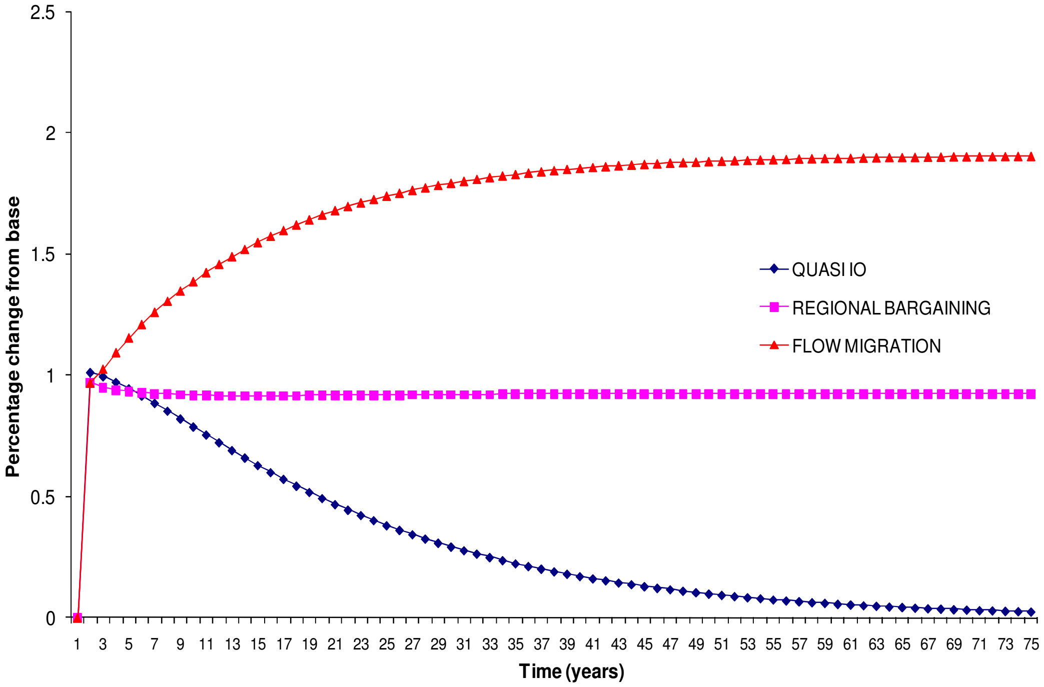


Figure G.11 Percentage change in Scottish total employment

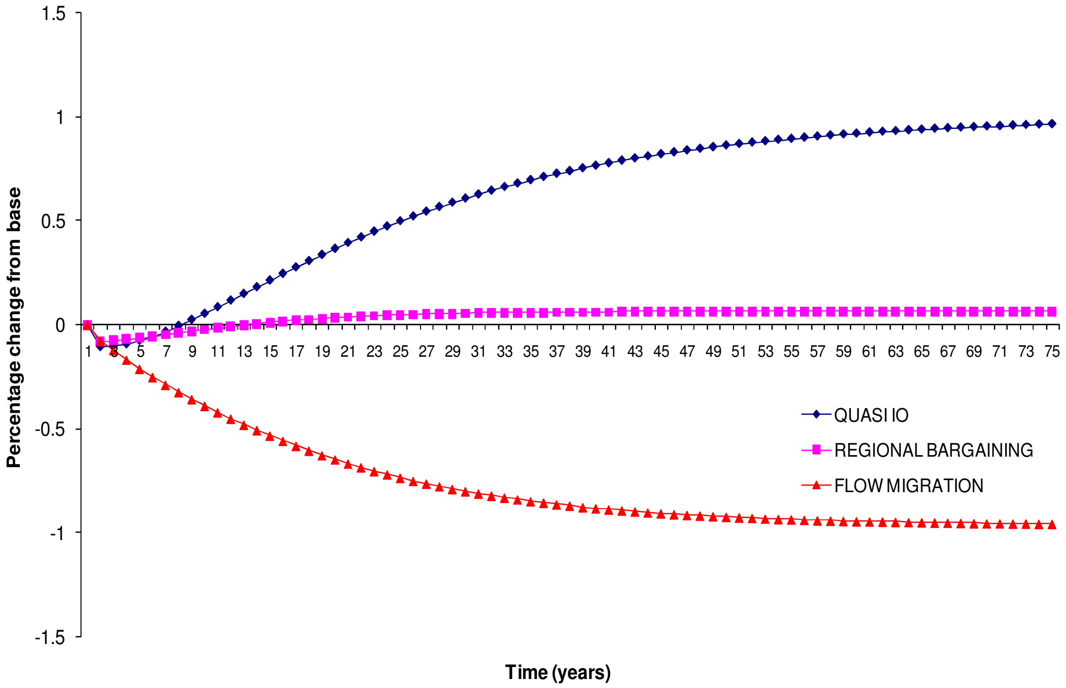


Figure G.12 Percentage change in Scottish real wage

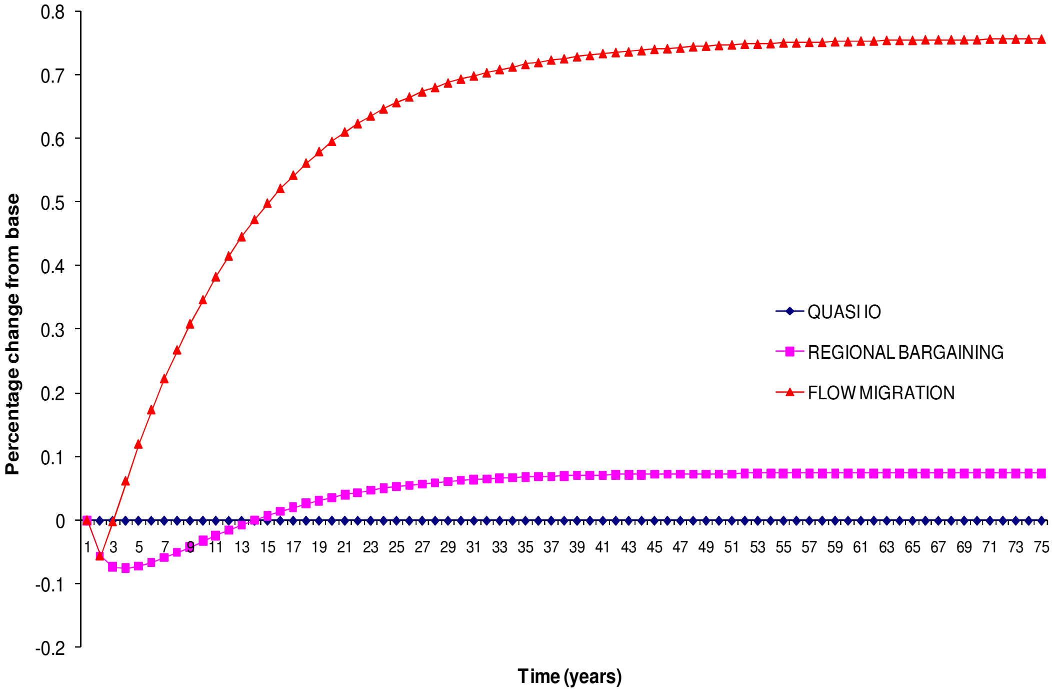


Figure G.13 Percentage change in Scottish exports to the RUK

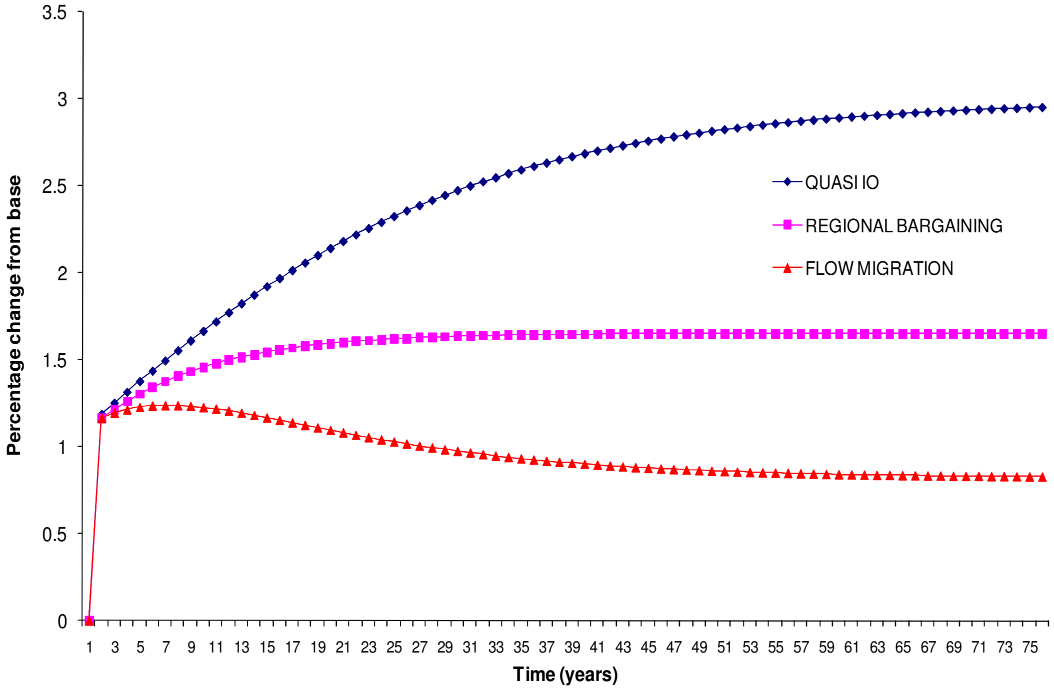


Figure G.14 Percentage change in Scottish exports to the ROW

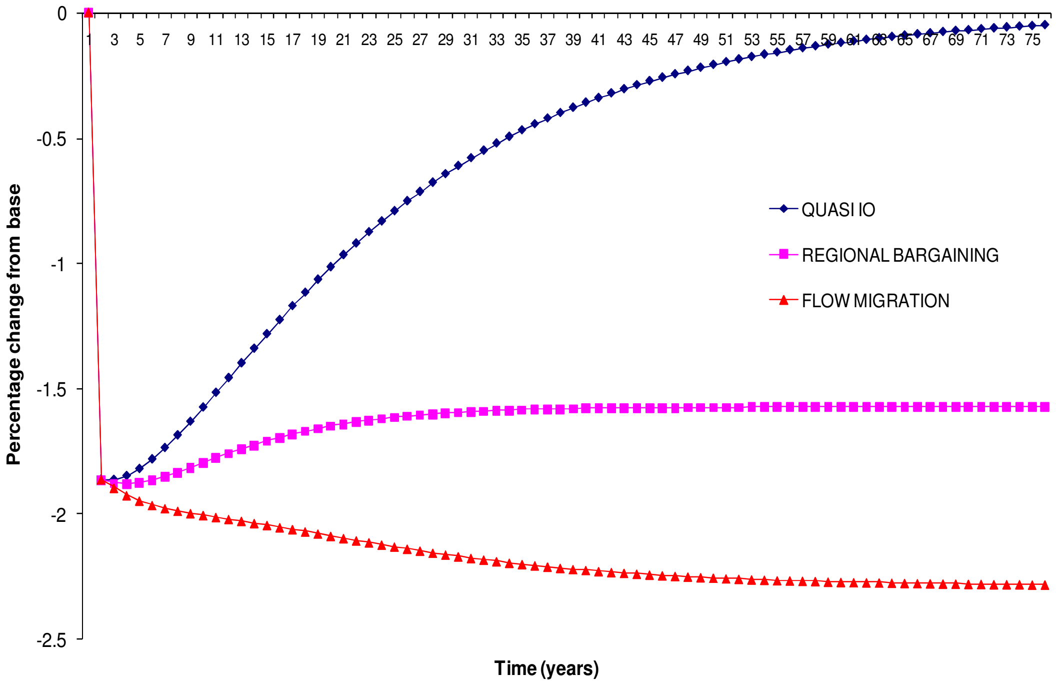


Figure G.15 Scotland's CO_2 'trade balance' with the RUK in the 10 years following the demand shock (tonnes, millions)

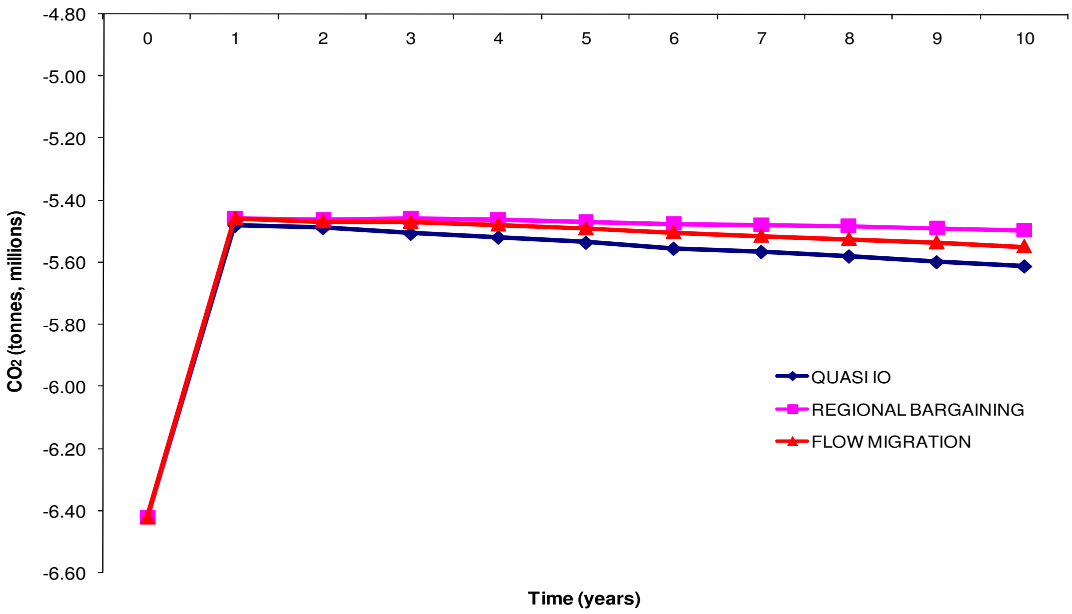
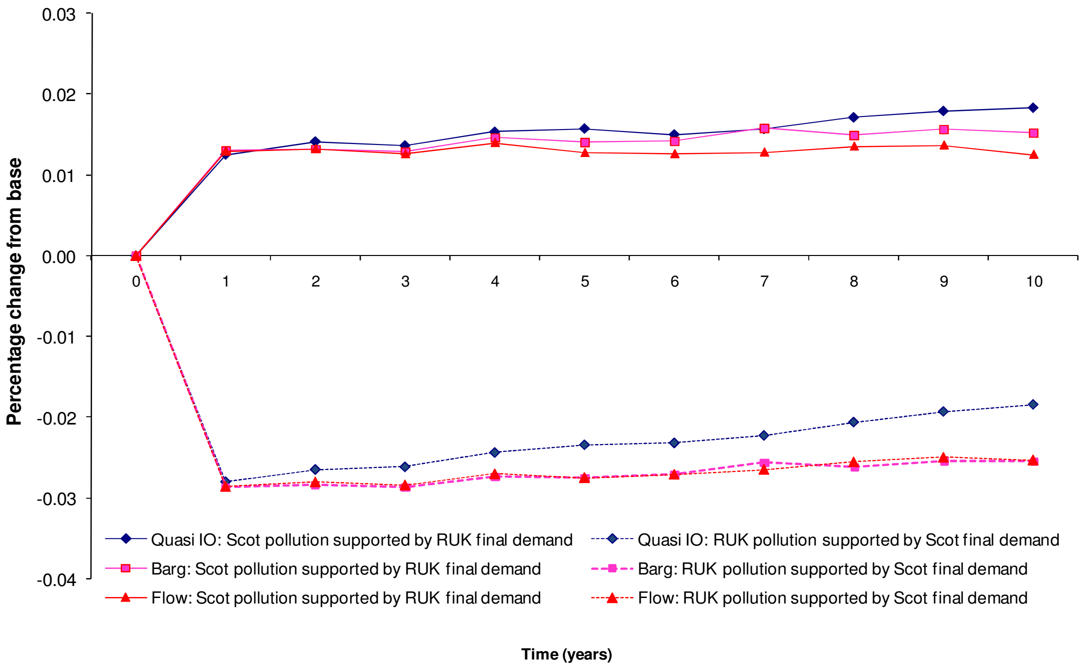


Figure G.16 The percentage change in CO_2 embodied in interregional trade flows between Scotland and the RUK in the 10 years following the demand shock



APPENDIX H: The UKENVI model

The UKENVI model is a UK-variant of the AMOS (Harrigan et al. 1991) CGE framework, with an appropriate sectoral disaggregation to allow for detailed analysis of energy-economy interactions. The UKENVI model has been used for various economy-energy-environment modelling applications (primarily relating to the economy-wide effects of an increase in energy efficiency – see Allan et al. (2007b), for example). The model description presented in this appendix resembles the standard AMOS/UKENVI accounts provided in the above mentioned papers, with some additional detail supplied here for the sake of clarity.

H.1 Model description

UKENVI is a CGE model of the UK economy and, like the AMOSRUK model used in Chapters 3-5 if this thesis, the model provides a flexible structure and a range of model closures corresponding to different time periods of analysis, labour market options, types of constraint and functional forms, as well as allowing for changes in key parameter values. This therefore allows alternatively-specified simulations to be conducted and compared.

The UKENVI model structure incorporates three transactor groups: households, firms and the government, and one external transactor, the ROW. There are twenty-five sectors/commodities, which are listed in Table H.1.

Table H.1: Sectoral aggregation used in UKENVI

UKENVI sector	Industrial activity	UK SIC (92) code[1]
1	Agriculture, forestry and fishing	1,2,5
2	Other mining and quarrying	11 to 14
3	Manufacturing: food and drink	15.1 to 16
4	Manufacturing: textiles	17.1 to 19.3

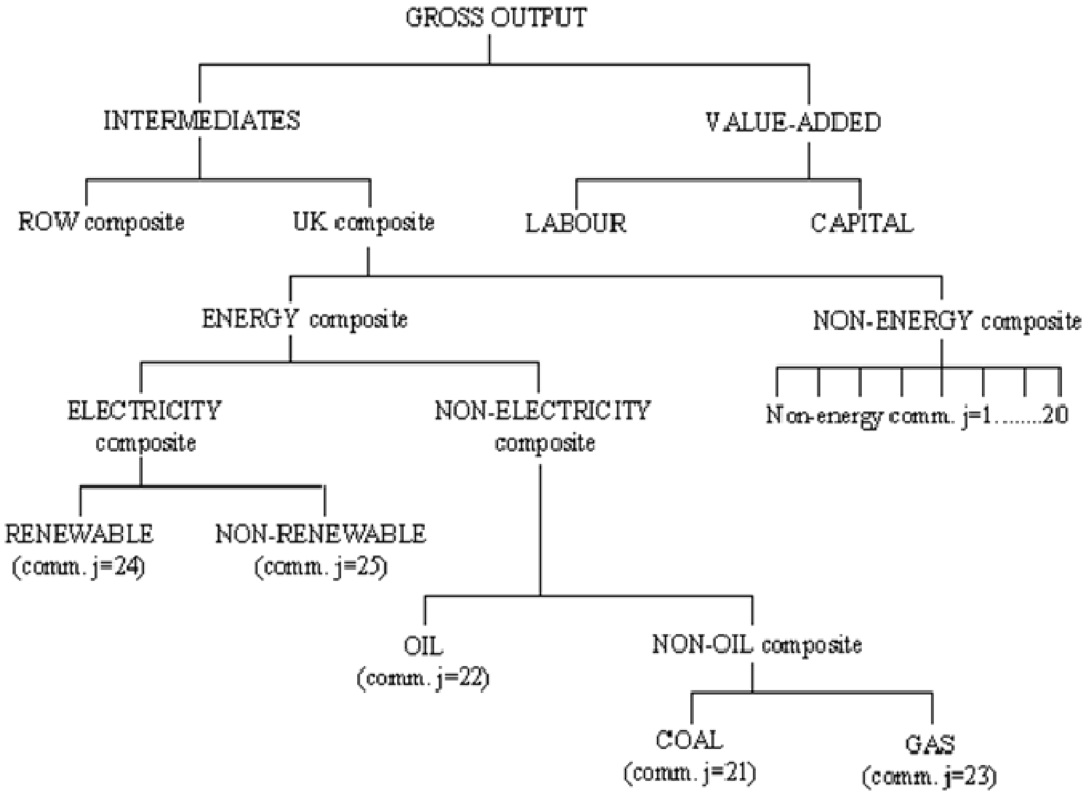
5	Manufacturing: pulp and paper	21.1 to 21.2
6	Manufacturing: glass and glass and ceramic products	26.1 to 26.4
7	Manufacturing: cement, lime and plaster	26.5 to 26.8
8	Manufacturing: iron, steel and casing	27.1 to 27.5
9	Manufacturing: other metal products	28.1 to 28.7
10	Manufacturing: other machinery	29.1 to 29.7
11	Manufacturing: electrical and electronics	30 to 33
12	Manufacturing: other manufacturing	20, 22, 24.11 to 25.2, 34 to 37
13	Water	41
14	Construction	45
15	Distribution and transport	50 to 63
16	Communications, finance and business	64.1 to 72 and 74.11 to 74.8
17	Research and development	73
18	Public administration and education	75 and 80
19	Health and social work	85.1 to 85.3
20	Other services	90 to 95
21	coal extraction	10
22	Oil processing and nuclear processing	23
23	Gas	40.2 to 40.3
24	Electricity - renewable	40.1
25	Electricity - non-renewable	40.1

[1] Standard Industrial Classification of economic activities (1992)

The model incorporates multi-level production functions (see Figure H.1), and cost minimisation in production. There are four main components of final demand: household consumption, investment, government expenditure and exports to the ROW. Consumption is a linear homogeneous function of real disposable income, government expenditure is taken to be exogenous, and exports and imports are generally determined via an Armington link, and are therefore relative-price sensitive (Armington, 1969).

The multi-level production functions are generally of the Constant Elasticity of Substitution (CES) type, so that there is input substitution in response to relative price changes. Leontief and Cobb Douglas specifications are available as special cases, and in the applications for Chapter 6, Leontief functions are specified at two levels of the production structure for each sector – the production of the non-oil composite and the non-energy composite – due to the presence of zeros in the base year data for some inputs within these composites. Otherwise, CES functions are used throughout.

Figure H.1: Production structure of each sector i in the 25 sector/commodity UKENVI framework



The different types of energy and non-energy inputs in the intermediates block of Figure H.1 are split according to the 'KLEM' (capital-labour-energy-materials) method that is most frequently adopted in the literature. At present, there is no consensus in the literature as to exactly where energy ought to be introduced in the production structure: for example, within the primary inputs nest (usually combining with capital: e.g. Bergman, 1988, 1990), or within the intermediates nest (e.g. Beasejour et al., 1994). In the UKENVI model, energy is placed with other intermediates, which seems most intuitive, since energy is a produced input. Alternative positioning of the energy input would, of course, affect the nature of the substitution possibilities between other inputs, and the empirical significance of this judgement is an issue worthy of detailed research.

There are no vintage effects in the model. Financial flows are not explicitly modelled. Interest rates are assumed to be fixed in the international capital market, so that the user cost of capital varies with the price of capital goods.

The model is parameterised to be in long-run equilibrium in the base year, implying that the capital stocks in each sector are fully adjusted to its desired level in the initial period. In the simulations in Chapter 6, the model is run on a period-by-period basis, as in the AMOSRUK simulations in Chapters 3-4. In this mode, in each individual time period the aggregate and sectoral capital stocks are fixed, whilst between periods, capital stocks are updated by investment, via an explicit capital stock adjustment mechanism. According to this process, investment equals depreciation plus some fraction of the gap between the desired and actual capital stock, where the desired capital stock is a function of commodity output, the nominal wage, and the user cost of capital. This method of capital accumulation is in line with a simple theory of optimal investment behaviour, given the assumption of quadratic adjustment costs. Thus, sectoral investment is influenced by the relationship between the capital rental rate (the competitive market rental rate for physical capital in each sector) and the user cost of capital (the total cost to a firm of employing a unit of capital). When the rental rate is above the user cost, desired capital stock exceeds the actual capital stock, thereby providing an incentive to achieve net capital investment. The ensuing capital accumulation leads to downward pressure on rental rates, thereby aiding the return to equilibrium. In the long run, the capital rental rate equals the user cost of capital for each sector, and the risk-adjusted rate of return is equalised across sectors. The long run is therefore a conceptual time period, where capital stock adjusts to its new desired level, given new values for sectoral value added, the user cost of capital, and the wage rate. However, when the model is run on a period-by-period basis with capital stock adjustment, a full updating of capital stocks to long-run values often takes in excess of twenty-five years. In Chapter 6, I conduct an eighteen-year simulation period, with a series of demand shocks entered in each of these years. This means that capital stocks are not fully adjusted over the period of consideration.

The model provides several alternatives for the precise specification of the labour market, each imposing a single UK labour market with perfect sectoral mobility. In the central case scenario in the analysis of Chapter 6, wages are determined via a bargained real wage function. In the sensitivity analysis, alternative labour market closures are considered: flow migration; exogenous labour supply; and a real wage resistance configuration.

The basic dataset for the model is a specially-constructed social accounting matrix (SAM) for the UK economy for the year 2000. In the absence of an officially-published UK analytical I-O table since 1995, this involved construction of an appropriate UK I-O dataset. The twenty-five sector SAM incorporates detailed manufacturing sub-sectors, as well as energy sub-sectors, including the division of the electricity sector between renewable and non-renewable generation. This required using an experimental disaggregation provided for Scotland, which was adjusted to account for the differences in electricity generation in the UK relative to Scotland.

A set of income-expenditure accounts for the UK for 2000 provided the income transfers data that are required to extend the I-O table into a SAM. This is developed on the principle of single-entry bookkeeping whereby expenditure items in one account are also recorded as income items in another. Five sets of income-expenditure accounts were constructed for households, firms, the government, and the ROW. Allan et al. (2006) provides full details on the construction of the UK I-O table and SAM used in the model.

The UK SAM for 2000 is used to parameterise the structural characteristics of the model. The elasticity of substitution for all sectors at all points on the multi-level production function take the value of 0.3, except where the Leontief functions have been imposed. The Armington trade elasticities for imports and exports are 5.0 for both renewable and non-renewable electricity, and 2.0 for all other sectors.

H.2 UKENVI model listing

Table H.2 presents a condensed version of the period-by-period AMOSRUK model used in this analysis, with the equations provided in general form.

Gross Output Price	$pq_i = pq_i(pv_i, pm_i)$	(H.1)
Value Added Price	$pv_i = pv_i(w_n, w_{k,i})$	(H.2)
Intermediate Composite Price	$pm_i = pm_i(pq)$	(H.3)
Wage setting	$w_n = w_n\left(\frac{N}{L}, cpi, t_n\right)$	(H.4)
Labour force	$L = \overline{L}$	(H.5)
Consumer price index	$cpi = \sum_i \theta_i pq_i + \sum_i \theta_i^{RUK} \overline{pq}_i^{RUK} + \sum_i \theta_i^{ROW} \overline{pq}_i^{ROW}$	(H.6)
Short-run capital supply	$K_i^s = \overline{K}_i^s$	(H.7)
Long-run capital rental	$w_{k,i} = uck(kpi)$	(H.8)
Capital price index	$kpi = \sum_i \gamma_i pq_i + \sum_i \gamma_i^{RUK} \overline{pq}_i^{RUK} + \sum_i \gamma_i^{ROW} \overline{pq}_i^{ROW}$	(H.9)
Labour demand	$N_i^d = N_i^d(V_i, w_n, w_{k,i})$	(H.10)
Capital demand	$K_i^d = K_i^d(V_i, w_n, w_{k,i})$	(H.11)
Labour market clearing	$N^s = \sum_i N_i^d = N$	(H.12)

Capital market clearing	$K_i^s = K_i^d$	(H.13)
Household income	$Y = \Psi_n N w_n (1-t_n) + \Psi_k \sum_i w_{k,i}(1-t_k) + \bar{T}$	(H.14)
Commodity demand	$Q_i = C_i + I_i + G_i + X_i + R_i$	(H.15)
Consumption Demand	$C_i = C_i\left(pq_i, \bar{pq}_i^{RUK}, \bar{pq}_i^{ROW}, Y, cpi\right)$	(H.16)
Investment Demand	$I_i = I_i\left(pq_i, \bar{pq}_i^{RUK}, \bar{pq}_i^{ROW}, \sum_i b_{i,j} I_j^d\right)$ $I_j^d = h_j\left(K_j^d - K_j\right)$	(H.17)
Government Demand	$G_i = \bar{G}_i$	(H.18)
Export Demand	$X_i = X_i\left(p_i, \bar{p}_i^{RUK}, \bar{p}_i^{ROW}, \bar{D}^{RUK}, \bar{D}^{ROW}\right)$	(H.19)
Intermediate Demand	$R_{i,j}^d = R_i^d\left(pq_i, pm_j, M_j\right)$ $R_i^d = \sum_j R_{i,j}^d$	(H.20)
Intermediate Composite Demand	$M_i = M_i\left(pv_i, pm_i, Q_i\right)$	(H.21)
Value Added Demand	$V_i = V_i\left(pv_i, pm_i, Q_i\right)$	(H.22)

NOTATION

Activity-Commodities

i, j are, respectively, the activity and commodity subscripts (There are twenty-five of each in UKENVI: see Table H.1)

Transactors

RUK = Rest of the UK, ROW = Rest of World

Functions

pm (.), pq(.), pv(.)	CES cost function
$\mathbf{k}^{\mathbf{S}}$(.), w(.)	Factor supply or wage-setting equations
$\mathbf{K}^{\mathbf{d}}$(.), $\mathbf{N}^{\mathbf{d}}$(.), $\mathbf{R}^{\mathbf{d}}$(.)	CES input demand functions
C(.), I(.), X(.)	Armington consumption, investment and export demand functions, homogenous of degree zero in prices and one in quantities
uck	User cost of capital

Variables and parameters

C	consumption
D	exogenous export demand
G	government demand for local goods
I	investment demand for local goods
$\mathbf{I}^{\mathbf{d}}$	investment demand by activity
$\mathbf{K}^{\mathbf{d}}$, $\mathbf{K}^{\mathbf{S}}$, K	capital demand, capital supply and capital employment
L	labour force

M	intermediate composite output
N^d, N^S, N	labour demand, labour supply and labour employment
Q	commodity/activity output
R	intermediate demand
T	nominal transfers from outwith the region
V	value added
X	exports
Y	household nominal income
b_{ij}	elements of capital matrix
cpi, kpi	**c**onsumer and capital price indices
d	physical depreciation
h	capital stock adjustment parameter
pm	price intermediate composite
pq	vector of commodity prices
pv	price of value added
t_n, t_k	average direct tax on labour and capital income

$\mathbf{u}$	unemployment rate
$\mathbf{w_n}$, $\mathbf{w_k}$	price of labour to the firm, capital rental
$\boldsymbol{\Psi}$	share of factor income retained in region
$\boldsymbol{\theta}$	consumption weights
$\boldsymbol{\gamma}$	capital weights