



**MODELLING THE IMPACT OF
POLICY AND OTHER
DISTURBANCES ON
SUSTAINABILITY POLICY
INDICATORS IN JERSEY: AN
ECONOMIC-ENVIRONMENTAL
REGIONAL COMPUTABLE
GENERAL EQUILIBRIUM
ANALYSIS**

VOLUME 1

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Thesis – PhD Economics

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Modelling the Impact of Policy and Other Disturbances on Sustainability Policy Indicators in Jersey: An Economic-Environmental Regional Computable General Equilibrium Analysis.

The aim of my thesis is to construct a multi-sectoral general equilibrium modelling framework with endogenous environmental variables. The function of this model is to track and help explain the movement of chosen environmental, or ‘sustainability’, indicators in response to policy changes and other disturbances to the economy.

Economic-environmental modelling has attracted considerable academic and policy interest around the world in recent years. The specific focus on modelling sustainability indicators constitutes a practical response to policymakers’ identification and use of individual and composite indicators to understand the environmental and social impacts of changes in economic conditions on the pursuit of sustainability objectives.

In this thesis I construct a multi-sectoral economic-environmental model of the Jersey economy. As well as providing the basis for calibrating the CGE model, the construction of the region-specific economic-environmental IO database provides a unique snapshot of the structure of pollution generation in Jersey. Specifically, I undertake comprehensive attribution analyses of the demand forces that drive pollution generation in Jersey, from both a Keynesian production-based and a neo-classical consumption-based perspective.

The main finding of the environmental IO analysis is that local household consumption is the main source of pollution generation in Jersey, indicating that the impact on real household income is a key factor in determining the environmental effects of changes in economic conditions and policy. The main sustainability concern in Jersey is the effect of an ageing population on labour supply and the economic and environmental impacts of in-migration to overcome this problem. Therefore, I develop a CGE simulation framework that is capable of identifying the effects of scarcity on the supply-side of the labour market in the presence of increased labour demand. I use this framework to analyse the impact of changes in population policy and demand conditions in the economy on environmental sustainability indicator variables.

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Chapter 1. Introduction

1. Background And Motivation

Modelling the impact of economic activity on environmental or other sustainability indicator variables is an area of research that is attracting considerable current interest and debate around the world, particularly since the publication of ‘the Brundtland Report’ (World Commission on Environment and Development, 1987). The Brundtland Report was the result of a United Nations General Assembly Resolution in 1983 on the issue of ‘sustainable’ economic development, with particular emphasis on concerns about environmental degradation, poverty and income inequalities in the global economy. However, political resolve on the issue of sustainability did not really emerge until about five years later as a result of the United Nations Conference on Environment and Development (UNCED), more commonly known as the ‘Earth Summit’, that was held in Rio de Janeiro in 1992. Almost all nations sent representatives to the Earth Summit. The main outcomes of this conference were ‘the Rio Declaration’ (setting out 27 general principles for sustainability - see United Nations, 1992), and Agenda 21, which is described as “a programme for action for sustainable development worldwide” (United Nations, 1992, p.3).

One of the key elements of Agenda 21 is what has become known as ‘Local Agenda 21’, introduced in Section 28 of the agreement on the following basis:

Because so many of the problems and solutions being addressed by Agenda 21 have their roots in local activities, the participation and cooperation of local authorities will be a determining factor in fulfilling its objectives. Local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and subnational environmental policies. (United Nations, 1992, p.233)

Following the commitments made at the Earth Summit, individual nation governments developed sustainable development strategies. The UK published its sustainable development strategy, 'Quality of Life Counts', in 1999 (DETR, 1999a) following a consultation process on the identification and use of a number of 'sustainability indicators', which include a number of environmental indicators. The actions of the UK national government have been reflected at the sub-national level, with the devolved administrations of Scotland and Wales and the English Regional Development Agencies (RDAs) beginning consultation processes on developing their own sustainability strategies and identification of environmental indicators. Moreover a number of regional and local authorities adopted their own Local Agenda 21 frameworks (see, for example, Fife Regional Council, 1995).

The development of sustainability strategies at the regional level in the UK is a logical step in light of the fact that a significant degree of responsibility for setting and achieving sustainability objectives has been devolved to the Scottish Parliament, the National Assembly for Wales and the English regional authorities. It has also been recognised that credible decision making on environmental issues, and sustainability in general, requires the development of an appropriate database and framework for analysis. Accordingly the Scottish, Welsh and English regional authorities have all begun a consultation process on the construction of regional economic-environmental accounts that will allow the identification and measurement of chosen environmental indicators and the subsequent development of frameworks for modelling changes in the indicator variables¹.

The aim of my thesis is to explore the issues involved in constructing an economic-environmental accounting and modelling framework for a small open regional economy and to develop an illustrative model for the target economy of Jersey. Jersey is a crown dependency of the UK (but an independent, self-governing state) that is located about 100 kilometres off the south coast of England. The selection of this particular target economy is made on the basis that I wish to focus on a region

¹ The National Assembly for Wales and English Regional Authorities have engaged in a joint consultation process with the UK Environment Agency. The Scottish Executive has set up its own

characterised by devolved powers and responsibility for sustainability. As I have explained above, UK regions now fall into this category. However, what makes Jersey a more attractive target economy for this study is the availability of unusually detailed environmental data. One of the main issues being addressed in the consultation process being carried out by the Scottish, Welsh and English regional authorities is the appropriateness of investing in region-specific economic and environmental data collection. By focussing on an economy that has already made this investment, a key output of my study will be the ability to reveal the value-added that is gained from collecting and using region-specific data.

Moreover, it is particularly convenient to take Jersey as the target economy as the present study is part of a wider modelling project commissioned by the States of Jersey from the Fraser of Allander Institute at the University of Strathclyde. The specific role of my thesis is to extend the economic model being constructed by the Fraser of Allander Institute to incorporate economic-environmental relationships.

Therefore, in this study, I identify Jersey as an empirical example of a small open regional economy characterised by devolved powers and responsibility for sustainability. Indeed, as an independent, self-governing state Jersey has full responsibility for the achievement of its stated commitment to sustainable development (States of Jersey, 1995). Jersey's interpretation of sustainable development focuses mainly on environmental concerns (pollution generation and resource use) and population issues (States of Jersey, 1998). The environmental concerns are both local and international in nature: for example the States' Environmental Charter, endorsed in 1996, includes a commitment to the principles agreed at the aforementioned Earth Summit, including the proposed adoption of a Local Agenda 21 framework (States of Jersey, 1998).

Given this policy emphasis on sustainable development, it becomes necessary to investigate the nature of economic-environmental relationships in Jersey for two reasons. First, any change in economic policies by the States of Jersey may, and

Scottish Environmental Accounts Working Group (SEAWG), taking advice from local agencies,

typically will, have environmental impacts. Secondly, in part because of its openness, the Jersey economy is subject to many non-policy shocks that are outwith the States' control, and these too will have accompanying environmental impacts. In fact, a further reason for selecting Jersey as the target economy for this study is that it has a number of distinctive features that make it of particular interest from an economic-environmental modelling perspective. In particular, while the Jersey economy can be regarded as highly open in terms of markets for goods and services, it is characterised by the existence of important supply constraints in its labour market, as discussed in the next section.

Therefore my objective is to construct a multi-sectoral modelling framework with endogenous environmental indicator variables. The function of this model is to track and help explain the movement of chosen individual and/or composite environmental variables (as indicators of sustainable development) in response to policy or other disturbances to the local economic system. In terms of the database used and the policy applications considered, my dissertation focuses on building a model for the target economy of Jersey. However, all the issues discussed and lessons learned have more general applicability for small open regional economies where devolved authorities have responsibility for setting and achieving sustainability objectives and which may be characterised by supply-side constraints.

2. Modelling The Jersey Economy

Jersey is the largest of the Channel Islands that lie to the east of the French Normandy coast, about 100 km south of the English mainland. In 1998 it had a population of around 89,000 people². While Jersey has been known as popular tourist destination and exporter of agricultural produce, its economy is in fact now dominated by its (largely externally-owned) finance sector³.

academics and the Environmental Accounts Branch of the UK's Office for National Statistics.

² Population estimate for the year 1998 provided by the States of Jersey

³ For example, in 1998 the 3 main finance sectors, Banks & Building Societies, Investment Trusts & Fund Managers and Insurance Companies (see Chapter 5, Section 5.1 for definition of sectors) directly accounted for 17% of employment, 28% of wage income and 50% of GDP in Jersey in 1998. In contrast, the Agriculture & Fishing sector only accounted for 4.3% of employment, 2.5% of wage

While Jersey is a crown-dependency of the UK it is also an independent, self-governing state. However the Jersey economy is very closely integrated with that of the UK, sharing its language, currency, exchange and interest rates. Moreover, the majority of Jersey's trade flows are with the UK⁴.

The size of the Jersey economy and its relationship with the UK and the rest of the world are important factors in deciding how it should be modelled. Given its size and openness to trade, Jersey is modelled here under the 'small open economy assumption'. This means that while Jersey has a relatively high degree of interaction with the rest of the world, via trade, its activity is assumed to have no significant impact on the rest of the world. For example, Jersey is assumed to be a price taker in all world markets. The small open economy assumption allows me to make the assumption that the rest of the world is exogenous, with the implication that only the target economy need be modelled. In terms of the environmental focus of my dissertation, the small open economy assumption is an important one because it allows me to assume that the global environmental impact of the Jersey economy is trivial. Thus it is reasonable to model the impact of the Jersey economy on the environment (e.g. the physical amount of pollution emitted into the environment from economic activities in Jersey) but to ignore any feedback effects from the world environment, which I assume to be negligible.

There is one other feature of the Jersey economy that has an important impact in terms of how I go about modelling it, namely the existence of supply constraints. The main constraint on economic activity in Jersey is on the supply-side of the labour market, which results from the States of Jersey's current policy of limiting in-migration to the Island. There are no migration controls as such; rather in-migration is limited through a policy (referred to as the Regulation of Undertakings) requiring that firms apply to the government for a permit before a new worker can be employed (even if this is to fill an existing post). Controls on the availability of

income and 1.3% of GDP. Tourist demand for local outputs directly accounted for 10.9% of employment, 6.1% of wage income and 5.1% of GDP. (See Fraser of Allander Institute, 2001a.)

housing (residency qualifications are required to buy property on the Island) and the absence of unemployment benefits are also regarded as deterring in-migration. The motivation for attempting to limit in-migration in this way is that placing limits on population growth is perceived as being essential for economic development to be sustainable, particularly because of the increased environmental and public spending pressures that are associated with an expanding population. However, it is feared that only allowing natural population growth is likely to lead to demographic problems, in particular the implication of a declining workforce given an ageing total population. Therefore a crucial element of model construction and specification in this study is the ability to reflect scarcity on the supply-side of the Jersey labour market.

Despite Jersey's status as a modern developed economy, which is mainly composed of service sector industries, and where the population, on average, enjoys a relatively high average standard of living, one important peculiarity is that, until now, national accounts have never been recorded for the economy⁵. In one respect this means that an important element of value-added from the current modelling project is the construction of an inaugural set of national accounts for the Jersey economy in the form of the input-output (IO) tables and social accounting matrix (SAM) that constitute the model database. However, the downside is that this means that no historical data are available for comparative purposes or for econometric estimation of parameter values and testing of model specification. The model is therefore calibrated to the base year dataset constructed here, with key parameter values being pre-specified on the basis of informed judgement and literature review, but subject to sensitivity analyses.

In terms of the environmental component of the model, the situation is somewhat different. Due to the existence of a single entry port to the Jersey economy and the

⁴ The primacy of trade with the UK is reflected in the fact that in 1998 transactions with the UK accounted for 47% of Jersey exports and 87% of imports (see Fraser of Allander Institute 2001a).

⁵ This may not be regarded as very peculiar in a regional context, as comprehensive economic accounting is more common at the national level. However, where a regional economy, such as Wales or the South West of England, is part of a larger national economy, such as the UK, there will be coverage of regional activity within the national accounts. In the case of Jersey, a very small but independent economy, this is not the case.

structure of the energy supply sector, it has been possible to build very detailed records on the physical amount of different types of energy imported into the economy and supplied to different types of user. Moreover, relative to other economies, the States of Jersey has invested heavily in environmental research. Specifically, the ongoing investment by the States of Jersey in the study and quantification of the nature of pollution problems in the economy is especially significant. This is illustrated by the existence of a number of reports commissioned over recent years on different aspects of pollution generation and Jersey's continued involvement in studies on energy use and pollution problems as part of the South West Energy and Environment Group⁶.

The existence of one study in particular, on sources of pollution generation in Jersey (Coley 1994) is extremely valuable for my purposes as it identifies emissions factors that can be applied to the aforementioned energy supply and use data to estimate base year pollution levels in the economy. All of this allows the construction of an unusually rich, region-specific economic-environmental database.

3. Dissertation Structure

My dissertation is structured as follows. In Chapter 2 I begin with an investigation of what policymakers mean when they state a commitment to sustainable development and how they propose to choose and use 'sustainability indicators' to monitor progress towards sustainability objectives. I argue that in order to understand and explain the movement of chosen sustainability indicators in response to changes in economic activity an appropriate model of the economy is required.

In Chapter 3 I consider the problem of specifying the type of economic model that will produce appropriate outputs for quantifying the impact of the economy on the environment. I argue that the basic requirement is for a multi-sectoral general

⁶ The South West Energy and Environment Group (SWEEG) is an alliance of local authorities in the South West region of England and the States of Jersey. The SWEEG funds ongoing studies into energy and pollution issues (orientated to the needs of the SWEEG participants) at the Centre for Energy and the Environment at Exeter University.

equilibrium model of the economy. An economic-environmental model should be multi-sectoral because energy use and pollution generation tends to vary radically across different types of activity. Moreover, it should be general equilibrium in nature because interactions and interdependencies between different sectors are crucial in determining the full environmental impact of the economy.

The earliest developments in modelling and accounting for economic-environmental interactions in a multi-sectoral general equilibrium framework are found in the input-output (IO) literature. I review this literature to see what lessons can be learned regarding the use and limitations of the environmental IO approach. My main finding is that most environmental IO applications tend to be limited to accounting for economic-environmental linkages and/or the impact of historical changes in polluting behaviour. However, I conclude that, with its assumptions of constant technical relationships and passive supply-side, the range of effects and disturbances that can be modelled within a conventional IO framework is limited. These limitations appear particularly important given my intended application of the framework I construct here to the supply-constrained Jersey economy. Therefore, in Chapter 4 I go on to review the economic-environmental CGE modelling literature to see what developments have been made within a more flexible general equilibrium framework. I find that there are two main areas of concern, both of which relate to model specification. The first is how energy use is modelled, particularly regarding possibilities for substitution between different types of energy and between energy and other factors of production. The second is how pollution generation is related to economic activity.

I then go on to apply the general lessons learned in the literature reviews of Chapters 3 and 4 to the development of an empirical model of economic-environmental interaction in a small open economy, using Jersey as an illustrative example. The process of developing the modelling framework for Jersey begins in Chapters 5 and 6 where I outline the process of constructing a consistent economic-environmental base year database for a multi-sectoral general equilibrium model. This involves constructing a social accounting matrix that describes the structure of the target

economy (for the illustrative example of Jersey) in the chosen base year (1998) as the core economic database in Chapter 5. Then in Chapter 6 I explain the construction of a set of environmental accounts, reporting physical energy use and emissions generation for the same sectoral breakdown as identified in the economic accounts. I use these accounts to identify a set of technical coefficients that relate the physical variables measured in the environmental accounts to the monetary variables recorded in the economic accounts.

At this stage I introduce an issue that I would argue is not given adequate attention in the economic-environmental modelling literature reviewed in Chapters 3 and 4. Most of the debate in this literature focuses on issues of model specification. However, an issue that receives very little attention is the quality of data available for modelling economic-environmental relationships and the appropriateness of using economy-specific data for this purpose. As I explain in Chapter 6, in the case of Jersey it is possible to construct a very rich and detailed set of region-specific, economic-environmental accounts, which allows me to derive a set of region-specific technical coefficients to both account for and model energy use and pollution generation by sector. This facilitates an assessment of the added precision that can be gained by using region-specific as compared to adjusted national coefficients in accounting for and modelling environmental problems at the regional level. I find that, in the case of Jersey, there would be significant errors even in simply accounting for total pollution generation in the base year if UK coefficients, representing national sectoral average energy-use and pollution intensities, were used.

In Chapter 7 I go on to explain the development of the simplest and most popular type of economic-environmental general equilibrium system – an environmental input-output system – again using the Jersey IO accounts as a specific example. I use the Jersey environmental IO system to analyse the size and nature of the pollution problem in the base year of 1998. Specifically, I use the environmental IO system to attribute pollution generation in the Jersey economy to elements of intermediate and final demand. I begin by adopting traditional Type I and Type II IO attribution methodology. Under this approach, the main issue is whether household

consumption is treated as being determined exogenously, as is the case with other components of final demand, or endogenously, by income from employment in the production sector of the economy. However, I argue that adopting this Keynesian perspective, where all pollution generation in the local economy is ultimately driven by production, is inconsistent with the environmentalist's view of the pollution problem, which is to locate the source and responsibility for pollution generation in human consumption choices. While a conventional single-region environmental IO system is not really an appropriate framework for developing a consumption-based measure of pollution generation, I attempt to improve the concept of attribution by adopting a neo-classical, rather than a Keynesian economic approach. The resultant neo-classical linear attribution system (NCLAS) treats exports as being determined endogenously (by import demand), and attributes all pollution generation in the economy to local private (household) and public (government) consumption (both of which are determined, and can therefore be influenced, locally).

However, while emphasising the usefulness of environmental IO analysis for accounting purposes, I conclude that the IO system is too restrictive for *modelling* economic-environmental interaction, particularly in a supply-constrained economy like Jersey. Firstly the use of fixed technical coefficients in production implies the assumption of zero substitutability among all inputs to production. Secondly, a conventional IO system, of the type constructed for Jersey in Chapter 7, is entirely demand-driven, with the inherent assumption of a completely passive supply-side. One implication of this is that there is no possibility of modelling supply constraints, which is crucially important in the case of Jersey. Ghosh (1958) has developed a supply-driven IO model, but this has been severely criticised by Oosterhaven (1988, 1989). In general I argue that it is preferable to model the impact of disturbances, such as changes in policy, in a framework where supply and demand simultaneously determine prices and quantities.

Therefore in Chapter 8 I proceed to the development of an economic-environmental computable general equilibrium (CGE) modelling framework, again using the Jersey economy as an illustrative empirical case. My argument is that the CGE approach

retains the multi-sectoral, data-driven perspective that is the key advantage associated with IO, but provides a richer, more theory-consistent approach to modelling the impact of disturbances to any economy. Specifically, both consumption and production are modelled using standard economic theory regarding substitutability between inputs/commodities (the IO case, where the values of all substitution parameters are assumed to be zero, is encompassed as a special case). Moreover, because both supply and demand are modelled as being responsive to changes in relative prices, it is possible to model competitiveness effects, which are likely to be very important in a small, very open economy like Jersey. The construction of a CGE modelling *framework*, where a range of model configurations and specifications are possible, also means that it is possible to examine the sensitivity of simulation results to the assumptions made regarding substitution and price elasticities. Finally, adopting a CGE approach makes it possible to explicitly model the adjustment path of the economy in response to a given disturbance, which is particularly important if the model is to be used to help inform policy.

In Chapter 9 I use the Jersey economic-environmental CGE model, referred to as JEMENVI⁷, to carry out a number of simulations in order to illustrate the fulfilment of the stated objective of this study. That is to say, model simulations focus on tracking and explaining the impact on environmental indicator variables resulting from several hypothesised disturbances to the Jersey economy. Specifically, the scenarios simulated focus on policy options relating to one of Jersey's key sustainability objectives – sustainable development under the constraint of limited migration and population growth – under different hypotheses about demand conditions in the economy. I also report the results of some initial sensitivity analyses, focussing on the sensitivity of the environmental results to what I assume about the elasticity of labour demand (given the importance of household income and expenditure as a source of direct emissions generation in Jersey).

Finally, in Chapter 10 I provide a summary of the dissertation and highlight the key novel elements of its contribution. The first of these is the construction and use of a

⁷ JEMENVI is an acronym for 'Jersey Economic Model, **E**nvironmental Variant'.

set of environmental coefficients based entirely on the use of region-specific data for Jersey, which greatly increase the precision of accounting for and modelling the environmental impacts of economic activity. The second is the development of an economic-environmental modelling framework that can be used to examine the types of trade-offs implied by adopting a policy commitment to sustainable economic development. This involves constructing a modelling framework that can be used to examine the economic and environmental impacts of disturbances to the systems. Thirdly, in the Jersey context I configure and use the model to simulate a specific set of policy scenarios, which focus on the impacts of changes in economic conditions in the presence of the supply constraints imposed by current population policy in what is already a tight labour market.

However, it is important to note that the applicability of the modelling framework that I develop here is not restricted to the case of Jersey or the specific type of policy application reported here. It is applicable to any small open regional economy where there is a need to analyse the movement of environmental indicators in response to changes in economic activity, particularly where the economy is subject to labour market constraints, and for a wide variety of policy applications. In particular, as I explain at the start of this chapter, the devolved regional authorities in the UK have expressed the same type of sustainability and environmental policy concerns as Jersey and a need to account for and model environmental indicator variables. Therefore I anticipate that the work I report in this dissertation will be useful in a wider UK context⁸.

⁸ In the case of Scotland, I am a member of the aforementioned Scottish Environmental Accounts Working Group and have been asked to advise the group on the basis of both the accounting and modelling work that I report here. I have also been involved in the development of an economic-environmental modelling framework, similar to the one constructed here, for Scotland – see, for example, McGregor *et al.* (2001b, 2001c).

Chapter 2. Sustainability in a Policy Context: Sustainability Indicators

1. Introduction

In this chapter I begin my study by examining the policy basis for the current interest in modelling economic-environmental interaction. In Chapter 1 I explain that this has arisen as a result of the commitment that governments around the world have made to the idea of ‘sustainable’ economic development. Therefore, the logical place to begin the study is with an exploration of what policymakers mean when they state a commitment to sustainability and how they intend to measure whether economic development is sustainable.

A central part of the sustainability question has been the argument that National Income as currently measured is not *sustainable* income, as it neither values environmental assets nor takes account of environmental degradation. Moreover, the costs of cleaning up environmental damage are treated as an addition to national income, while no account is taken of the welfare loss caused by the damage in the first place. This has led to efforts to find ways to adjust measures of national income to take account of economic-environmental interdependence. However, due largely to the problems of valuing natural/environmental resources and accurately measuring the depreciation of natural capital, replacing the conventional system of national accounting with a ‘Green GDP’ or ‘sustainable income’ would be problematic and controversial¹. Instead there have been various proposals for systems of **satellite accounts**, which would exist alongside conventional National Income accounts, providing information to help manage economic activity in a way that is sustainable. A key proposal for satellite accounting has been for the use of **sustainability indicators**: systematic and regular reporting of movements in a number of economic, environmental and social indicators. Where valuation is difficult, as in the case of environmental factors, satellite accounts, unlike the idea of a fully integrated Green

¹ In fact, I am part of a research team that is being funded by the ESRC to explore measurement and modelling of Green GDP for Scotland.

GDP or sustainable income, allow measurement in physical units, with no necessity that these be converted into monetary units.

Both the UK and Jersey have published consultation documents (see DETR, 1997, 1998a, 1998b, 1999a, 1999b, and States of Jersey, 1998) on the question of sustainable development, including proposed sets of sustainability indicators. What I intend to do in this chapter is to identify and consider the main issues arising from the UK's and Jersey's discussions and proposals on the choice and use of sustainability indicators, and how modelling using an economy-environment computable general equilibrium (CGE) framework can help address these issues.

First I examine the concept of sustainability and the role of sustainability indicators: in Sections 2 and 3 I respectively consider the definition of sustainability and the sustainability objectives. Sustainability objectives are a pre-requisite for sustainability indicators and provide the framework in which these are used. In Section 4 I examine the proposed use of sustainability indicators for monitoring progress towards stated sustainability objectives. I then go on to examine the questions raised and conclusions reached by both the UK and Jersey governments with respect to the type and number of indicators that should be used. In Section 5 I consider the question of individual versus composite indicators. Then in Section 6 I discuss the main types of composite indicators compiled to date, and take a closer look at some of the issues involved. In Section 7 I focus on the main questions arising in consultation documents over the more common approach of using sets of individual indicators, first examining the proposed number of individual indicators, then the classification of types of indicator. Finally, in Section 8 I give a summary and conclusions of the issues discussed in this chapter, including the proposed role of CGE modelling in addressing the policy concerns identified here.

2. Defining Sustainability

2.1 Types Of Definition

There exists no agreement on a definitive definition of what is meant by sustainability and sustainable development. Therefore the first step of identifying precisely what is meant when a country states a commitment to sustainability is not easy. One problem is that there seem to be at least two different *types* of definition of sustainability. Some are fairly focussed in that, while they may not meet with universal agreement in terms of content, it would seem possible, in principle at least, to put them into operation by stating achievable objectives and then acting to achieve them. Others seem more like mission statements, which, while unobjectionable in spirit, seem impossible to put into practice because of conceptual problems. For example, the statement contained in the UK government's 'Opportunities for Change' consultation document (DETR, 1998a, paragraph 6), and repeated in the first paragraph of the more recent 'Quality of Life Counts' (DETR 1999a), that

Sustainable development is a very simple idea. It is about ensuring a better quality of life for everyone, now and for generations to come.

While one cannot fault the sentiment of this statement, how could sustainable development as defined in this way ever be achieved? If the current course of development is, as seems commonly agreed, unsustainable in some way, this suggests a need for some policy action to get on a course that *is* sustainable. However policy inevitably involves **distributional effects**, which means that a resulting situation where *everyone* (across space and time) is made better off is highly unlikely. For example, national policies may have distribution effects within the country in question, such as the UK government's 'accelerator' policy on fuel duties. This policy provoked a great deal of negative reaction from the public (especially in rural areas), and from motoring and road haulage organisations, which all judge it to be unfair to one party or another. On an international level, multilateral policy actions for environmental protection are often seen as unfair to developing countries, which, quite reasonably, argue that they should be afforded the same opportunities to develop as the now developed countries enjoyed. However it is argued that this is not possible if they must meet global standards on, for example, CO₂ emissions. This highlights another reason why the issue of distribution is an

important one: not only will policies with inequitable effects make sustainability hard to achieve, inequality in itself may cause development to be unsustainable. For example, if the effects of a global agreement to cease the depletion of the ozone layer, with the intention of making the world economy more sustainable, were to harm the development of an emerging economy, this may make the emerging economy unsustainable. Another example, on a national level, is the possible causal relationship between an inequitable society and crime: if a country's policies have effects which increase inequality this may lead to a rise in crime, making the quality of life there unsustainable. If the link between equality and sustainability is accepted, this also reinforces the implications for the UK statement above: if movement towards sustainability requires a redistribution of income to eliminate inequality this would involve the circumstances of poorer groups improving at the expense of richer groups.

There is also the question of inter-generational distribution: what if the change in behaviour necessary to move to a more sustainable path of development involves cutting current consumption? This would make the current generation worse off in order to make future generations better off. Would this not be politically infeasible for governments who are elected by the current generation, but are responsible for making sustainability policy to ensure better standards of living for both current *and* future generations? Moreover, even laying aside distribution effects, it is not clear how the preferences and welfare functions of future generations, or the technology that will be available to them, can be predicted by those responsible now for making sustainability policy to ensure their better standard of living.

However, as stated above, there are narrower definitions of sustainability that are, at least in principal, more practical and provide focus for policymakers to form objectives for operational policy. Both the UK and Jersey cite the 'Brundtland' definition of sustainable development² as (DETR, 1998a, paragraph 8, and States of Jersey, 1998, page 7):

² The concept of sustainable development gained prominence in 1987 with the publication of what is known as the Brundtland Report (World Commission on Environment and Development, 1987). This report is officially titled 'Our Common Future', and was produced by the World Commission on

development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

This allows a definition of sustainability from which practical principles can reasonably be derived. A minimum condition for ensuring the ability of future generations to meet their needs (bearing in mind that current policymakers cannot know with any certainty what these needs will be or the technology that will be available) is to maintain the productive capacity of the system. In other words, to preserve for future generations the *potential* to enjoy the same quality of life as the current generation has had. Productive potential at any time depends on the stock of productive assets, the capital stock, available for use. Thus sustainability would seem to involve not running down that stock of assets, which will include both man-made capital (physical, human and intellectual) and natural capital (services offered by the environment which facilitate economic activity and human existence). This would be consistent with a Hicksian definition of sustainable income as being the amount that can be consumed during the accounting period without leaving us worse off at the end of the period than we were at the beginning. It would also mean that sustainability involves not eroding the capital base of the system, instead living off the returns to that capital. The argument for not eroding the *natural* capital base of the system in particular is based on the argument of limited substitution possibilities between natural and man-made capital. This type of definition suffers from the practical problem that I mention in the introduction to this chapter, that of valuing and measuring the depreciation of natural capital. However this type of problem can to some extent be tackled in practice by the use of such tools as sustainability indicators and critical thresholds. The same cannot be said for the type of conceptual problems raised above with regard to the ‘mission statement’ type definition.

2.2 Types Of Sustainability

Environment and Development (WCED), a body set up by a UN General Assembly Resolution in 1983. The Chairman WCED was Gro Harlem Brundtland, former Minister for the Environment, and Prime Minister, of Norway, which is how the report gained its popular title.

A second issue is what any one government actually *means* when it expresses a commitment to sustainability. Again the possible answer falls into one of two broad categories, but these often get conflated in discussions of sustainability (the case in both the UK and Jersey consultation documents). First there is the type of sustainability that is only really meaningful on a global level: economic development without risk of a global systems collapse due to overuse of natural resources and/or pollution/waste generation beyond the carrying capacity of the environment. This is the type of sustainability concern raised by Meadows *et al* (1972) in ‘The Limits to Growth’. Using a formal systems analysis model of the world, Meadows *et al* (1972) predict limits to continued world economic growth within the next one hundred years “if the present growth trends in world population, industrialisation, pollution, food production, and resource depletion continue unchanged” (p.23). Achieving sustainability in this sense implies the requirement of full multilateral co-operation and participation to pursue economic development under a set of **sustainability constraints**, all of which are binding (i.e. if any one of the constraints necessary for sustainability is broken the system becomes unsustainable³).

The other thing that a government may mean by commitment to sustainability is commitment to maintaining the *quality of life* enjoyed in the country it is responsible for. This is of course inexorably connected to the issue of global sustainability, since the quality of life in any one country will be affected by the risk of global system collapse. However, while unilateral action on global sustainability is likely to have little effect (especially where the country in question is small, as in the cases of the UK and Jersey), there is a great deal an individual government can do to preserve the quality of life in its own country. Moreover when sustainability is interpreted in this way, unlike in the case of global system sustainability, there is no set of jointly binding constraints. Policymakers can make trade-offs between different factors which affect the quality of life depending on the preferences of the people who live

³ Sustainability agreements, such as international standards, may also be legally binding, or it may be that countries voluntarily choose to meet given targets as binding constraints on their development. Jersey is not individually committed to international agreements such as those made at the 1992 Earth Summit in Rio de Janeiro; rather it voluntarily chooses to commit to agreements made by the UK. One such commitment, resulting from the 1992 Earth Summit, is Jersey’s proposed establishment of a Local Agenda 21 framework to achieve the agreed principles of sustainability at the local level (see Chapter 1, Section 1)).

in the region they are responsible for⁴. Achieving sustainability in *this* sense implies economic progress according to some **social welfare function**, including all factors that affect the quality of life (including environmental conditions), weighted according to preferences. Of course a key point is that such a function should, in principle, incorporate the preferences of future generations, as well as those of the current generation; a point which would make the construction of such a function very problematic in practice⁵.

The ‘quality of life’ interpretation of sustainability is likely to be of over-riding importance to policymakers in a small economy like Jersey. The existing, relatively high, standard of living and good environmental conditions are likely to be the primary reasons why the resident population chooses to live and work on the island on the first place. Moreover, quality of life factors, such as the quality of the Island’s environment, are regarded as a primary resource for Jersey’s tourism industry. The fact that Jersey is a small island community also means that its policymakers have a relatively high level of control over the quality of life enjoyed on the Island. However Jersey is also an example of how the sustainability argument involves consideration of elements of both the quality of life and global sustainability approaches. The state of the global system will impact on quality of life in Jersey and commitments to international agreements on global sustainability will place a number of constraints on the Island’s economic activity. Moreover, there is also a connection to global sustainability in terms of the true impact of Jersey’s economic activity on the global system. If an economy imports inputs to production and/or goods and services to final demand the issue of ‘importing sustainability’ arises, since imports are likely to embody resource use and/or pollution in the country of origin. In the case of Jersey, where the electricity supply is largely imported from France, this issue is particularly relevant.

⁴ The notion of different types of sustainability concern implying progress either with or without the possibility of trade-offs may link back to the idea of the substitutability/complementarity of physical and natural capital.

⁵ Measures such as Green GNP and Genuine Savings do constitute an attempt to take into accounts the needs of future generations by taking into account depreciation of both man-made and natural capital. In particular, the Genuine Savings measure (Pearce and Atkinson, 1993, and Hamilton, 1996) is an attempt to measure sustainable income in the Hicksian sense (see Section 2.1) above. However, neither attempts to measure or incorporate the *preferences* of future generations.

In this section, then, I have identified two different types of sustainability concern: concern for the sustainability of the global system and concern over maintaining the quality of life enjoyed in a given economy. However we should note these are not categories that all sustainability concerns can be sorted into. Rather they give a *framework* for thinking about sustainability. There will be grey areas between the types of global and local level concerns identified above, and whether sustainability means development under a set of jointly binding constraints, or whether there can be trade-offs according to some social welfare function.

Take, for example, the idea of the sustainability of the global system, meaning that development must take place under a set of binding constraints: this type of sustainability concern could also apply at the local level. An example of this is the case of fish stocks, where over-fishing may lead to the collapse of a local economy⁶. In the case of renewable resources sustainability means accepting the constraint that the harvest rate must not exceed the regeneration rate of the resource in question. Over-fishing in local waters may not affect the global system, since at the global level the harvest rate may remain within the constraint of being less than or equal to the natural reproduction rate of the type of fish in question. However if the constraint is broken at the local level the local system in question will become unsustainable if it is reliant on the fishing industry. Again, as argued above, this will also affect quality of life in the local economy, and if the benefits from the fishing industry are considered important to the quality of life in a given local economy this would be reflected in any welfare function constructed for that economy. However the point is that if over-fishing means a risk of local system collapse, then it will be a factor which cannot be traded-off against something else, instead constituting a binding constraint on activity.

Another point is that in practice there may be various layers of government concerned with decision-making for sustainability. For example, at the international

⁶ Note that the example of fish stocks is a purely illustrative one. I claim no in-depth knowledge of fishing and the movement of fish stocks and am aware that there may technical problems with the example.

level greenhouse gases emissions are a global sustainability concern. Conversely, at the local level a government like that of Jersey, where greenhouse gas emissions are mainly in the form of traffic emissions, the main concern is more likely to be the effect on the quality of life of heavy traffic. The question is whether sustainability constraints are binding at the level in question: e.g. if a country like Jersey is committed to an international agreement on greenhouse gas emissions then this becomes a binding constraint as well as a quality of life issue.

3. Sustainability Objectives

3.1 The UK's Sustainability Objectives

Having defined what it means by sustainability, the next logical step for a government would seem to be to identify a set of objectives to which it is committed and which it is capable of attaining. Sustainability indicators can then be used to monitor progress towards meeting these objectives. The UK government states four broad objectives for sustainable development in the DETR's (1998a) 'Opportunities for Change' consultation document (paragraph 9) under the headings:

1. "Social progress which recognises the needs of everyone"
2. "Effective protection of the environment"
3. "Prudent use of natural resources"
4. "Maintenance of high and stable levels of economic growth and employment"

The wording of these four objectives implies that they relate broadly to distribution (headings 1 & 4), use of natural resources (3), pollution/environmental protection (2), and economic progress/performance (4). Within these broad categories sustainability concerns also appear to be of both types discussed above in Section 2.2: quality of life in the UK (1, 2, 3 & 4), and global sustainability (2 & 3).

The four objectives are restated in the later 'Sustainability Counts' consultation paper (DETR, 1998b, paragraph 3.1) along with the statement that

Achieving sustainable development means addressing all of these objectives equally, for both present and future generations.

Two initial points can be made. The first is to reiterate one of the arguments I have raised in Section 2.1. This is that it is unclear how the current UK government can properly address these objectives in the interests of future generations when it has, at best, incomplete information regarding the preferences of, and technology available to, those future generations. The second is that the proposed set of sustainability indicators⁷, and in particular the set of ‘headline indicators’, do not seem to address the stated objectives evenly, with neither distribution nor resource-use being adequately addressed⁸. Moreover, where indicators *are* proposed under the objective headings, it is questionable as to whether they properly address the concerns stated. For example, in the case of the headline indicator on ‘Education and Training’ the statement is made that “a key sustainable development objective is to develop a ‘learning society’ in which everyone routinely expects to learn and upgrade skills throughout life” (see DETR, 1998b, Section 11). The proposed indicator for this is ‘Qualifications at age 19’. However in a society with average life expectancies of 74 years for men and 79 years for women, the majority of which would be expected to be spent in the workplace, this would not appear to provide the appropriate information for monitoring progress towards this “key” objective. I will return to these points on the scope and suitability of the proposed UK indicators below, when the discussion moves on to types and numbers of indicators in Section 7.

3.2 Jersey’s Sustainability Objectives

Jersey’s consultation document on sustainable development (States of Jersey, 1998) does not lay out a definitive set of sustainability objectives in this way, and so it is difficult to assess the scope and suitability of the proposed set of indicators given in

⁷ The full set of proposed UK indicators is given in DETR (1999b), and the proposed headline set is detailed in DETR (1998b). Both are updated in the more recent document ‘Quality of Life Counts’ (DETR, 1999a).

the report. The bulk of the document is, however, devoted to detailing a set of ten “Key Strategic Aims”, which do encompass, to varying degrees, the areas of economic progress/performance, use of natural resources, pollution and environmental protection, and distribution. These strategic aims should ultimately lead to the formation of policy objectives. They will largely result from a public consultation process that is still ongoing in Jersey, and the whole process will contribute to the formation of the States’ policy regarding sustainability which in turn will become Jersey’s sustainability objectives⁹.

In anticipation of a final statement of objectives, it can be said that Jersey’s sustainability concerns, like those of the UK, involve elements of both global sustainability and quality of life in Jersey itself. In terms of environmental objectives, these relate to both local and international concerns. For example the States’ Environmental Charter, endorsed in 1996, includes a commitment to the principles agreed at the Earth Summit in Rio de Janeiro in 1992 regarding greenhouse gas emissions (States of Jersey, 1998). From my discussions with local civil servants and policymakers, local concerns seem to relate specifically to issues like traffic-related energy-use and pollution generation, particularly with respect to air quality in the main urban area (St Helier) and constraints on the supply of natural resources, such as water.

However Jersey’s primary concern appears to be that of population control, which is perceived as the key to most of the Island’s sustainability problems. The Key Strategic Aim relating to population is stated as “a permanent resident population the same or less than the current (September, 1995) level” (States of Jersey, 1998, p.25). This population level is around 85,000. This aim already forms part of the States of Jersey’s current population and immigration policy (adopted in November 1997). As I have noted above, this policy regarding population has arisen as result of the public consultation process. One key finding from a series of meetings and questionnaires is

⁸ In the later ‘Quality of Life Counts’ document (DETR, 1999a), which provides a benchmark set of results for the full set of indicators, the sub-set of headline indicators outlined in DETR (1998a) is expanded to include new indicators for “poverty and social exclusion” (Summary, p.1).

⁹ At the time of writing a policy document on Jersey’s sustainable development strategy is being prepared for submission to the States of Jersey.

reported in the States of Jersey Policy and Resources Committee's '2000 & Beyond: Strategic Policy Review 1995' document (States of Jersey, 1995). Here it is stated that (of those participating in the process) "71% would like to see the size of the population of the Island stay the same or decline a little over the next ten years" (p14). Since 1995 job growth and natural increases have meant that the current population is now above this level (at around 89,000). However Jersey remains committed to this policy objective, with the view that sustainability policy will not be achieved if population growth is not controlled.

Several questions arise, the first being how legitimate an objective population control actually is for sustainability. Is this a necessary condition for sustainability? If so, is it a question of level or density (in rural/urban areas) of population? A recent population policy document (States of Jersey, 1999) states that "The Island cannot go on accepting population growth without serious consequences for the quality of life and the environment" (page 7, paragraph 9). It goes on to state that "The current pressures on housing, education facilities, road space are all a reflection of the impact of population growth" (also page 7, paragraph 9).

However a second question is whether the particular target population level of 85,000 is the *optimal* level of population for the Island, since it would seem that this target level simply reflects the stated preferences of the existing population. While in the aforementioned population policy document (States of Jersey, 1999), concerns are stated over the pressures caused by increasing population, it also recognised that population control will in turn have implications for the level of economic activity through supply constraints on the labour market. One particular concern is that this may in turn lead to inflationary pressure in the economy. So it does appear to be recognised that the preferred level of 85,000 (which, based on recent figures, implies the need for a *decrease* in population) may not in fact be the *optimal* population level for Jersey.

4. The Role of Sustainability Indicators

4.1 The Proposed Use Of Sustainability Indicators In The UK And Jersey

The UK's 'Opportunities for Change' consultation document (DETR, 1998a) introduces sustainability indicators in a section titled "Keeping track of progress" (paragraph 16) and invites "views on a set of key indicators of sustainable development"¹⁰. The resulting "comprehensive core set" is given in the 'Monitoring Progress' document, and a set of 'headline' indicators intended to provide an "overview" of progress are detailed in DETR (1998b), where further views are invited. The result of the consultation process is the 'national set' of sustainability indicators, for which an initial quantitative assessment of progress is given in DETR (1999a) (the first annual review of progress is given in DETR, 2001). Jersey also introduces sustainability indicators as a way of providing information to allow progress towards meeting sustainability objectives to be monitored.

The first question then is whether the indicators proposed are capable of fulfilling this role. As I have stated above, it is difficult to answer this question in the case of Jersey since the process of setting objectives is still ongoing. However in the case of the UK it seems that the answer must be 'no', particularly in the case of the 'headline' indicators, which, as argued above, do not address all the objectives evenly or adequately.

For example, for the objective of "prudent use of natural resources", DETR (1998b) only propose one headline indicator, dealing with waste and waste disposal on the basis that excessive production of waste may be a symptom of inefficient use of resources. DETR (1998a) acknowledges that waste generation may not be an adequate proxy for efficiency in resource use and explains that the Government is considering ways of measuring *total* resource consumption in the UK. However methodological difficulties are cited as the reason why a resource use indicator is not included among the proposed headline set. These include the question as to how meaningful it would be to add together volumes of very different resources, whose

¹⁰ More formally, an advisory group, the UK Round Table on Sustainable Development (originally established in 1995) is involved on an on-going basis in assessing the UK government's choice and

extraction, use and disposal have very different effects on the environment. The reasoning here is somewhat confusing since a simple solution would seem to be to have individual indicators for different resources, the use and disposal of which are thought to be significant to the economy in question and/or to global sustainability. Data do seem to be available on the use/extraction of several natural resources as the proposed fuller set of indicators listed in DETR (1999b) includes indicators, amongst others, on the depletion of fossil fuels and water demand and availability.

There also appears to be some inconsistency in the UK's choice of headline indicators. Both the States of Jersey (1998) and DETR (1998b) consultation documents give broadly similar lists of selection criteria, most of which seem valid enough (including factors such as data availability and reliability). However in the case of the UK, while the non-inclusion of resource use indicators is justified by data and methodological problems, other proposed headline indicators that do make the list, such as one on health – “expected years of healthy life” – clearly suffer from data and methodology problems of their own. The methodology for the health indicator is still being developed, which raises the question of how it can be considered to be sufficiently technically robust to qualify as a headline indicator while indicators on resource use are not.

4.2 Targets For Sustainability

Leaving aside the specific case-related problems above, the principle issue for choosing sustainability indicators is making sure that they are appropriate to fulfil their role as a means of monitoring progress towards meeting sustainability objectives. I have argued that indicators should be chosen on the basis of a well-defined framework of objectives that must be met if sustainability (the interpretation/definition of which for the economy in question should be clear to all concerned) is to be achieved. The objectives will become standards to be met, which will in turn allow targets to be set. Targets may be exogenously decided: in

use of sustainability indicators and recommends issues for consideration by the Sustainable Development Commission.

particular, where global sustainability is concerned, targets may be set as part of international agreements.

For example, both Jersey and the UK are parties to various agreements on limiting emissions of greenhouse gases. Where such agreements exist, these targets will represent the type of binding sustainability constraint discussed in Section 2.2. A full set of global sustainability targets, which would represent the full set of binding sustainability constraints, as discussed in section 2.2, does not yet seem to exist for either Jersey or the UK, but this could be expected to involve identification of critical levels, safe minimum standards etc.

Individual (regional or national) governments may also decide to set their own targets where global sustainability issues are concerned. This may be the case where no international agreements exist but governments are unilaterally concerned, either because of concern for the local environment or because their electorates express concern over global sustainability. It is also often the case that individual governments may use international agreements as a minimum target and set a more ambitious target for domestic activity (or regional governments may adopt national targets as a minimum standard and set higher ones for local activity). For example the EU has set a requirement that the UK reduce its emissions of the major greenhouse gases by 12.5% on 1990 levels by 2010, but the UK has indicated that it will seek a higher reduction of 20%. In the case of 'Quality of Life' targets, local policymakers would be expected to set these according to local preferences, ideally those of the people living in the economy, whose quality of life is in question. (The preferences of the local population could be elicited through a process of public consultation and then used to build some type of social welfare function.)

Once targets are in place the role of sustainability indicators is to monitor how far away actual behaviour is from sustainable levels. Ekins & Simon (1998) refer to this as the 'sustainability gap'. While sustainability indicators will mostly be stated in physical units, Ekins & Simon argue that the physical sustainability gap can be given a monetary value according to the expenditure on abatement/restoration required to

close the gap between actual and target levels¹¹. However they note that “whole-economy modelling....which would take account of economic feedbacks and interactions” (Ekins & Simon, p.161) would be necessary to calculate the economic costs of closing the sustainability gap in this way. Note that this would go further than what would normally be termed an accounting exercise.

5. Individual And Composite Indicators

Both the UK and Jersey consider the feasibility of (i) sets of individual indicators of different key variables, and (ii) the notion of composite indicators incorporating different factors, including economic, social and environmental inputs, into a single index of sustainability and welfare. This is often set up as a question of one versus the other. For example a common argument in the literature (and in the DETR's, 1998b, consultation document) is that composite, or aggregated, indicators are not scientifically valid or technically robust. The basis of this argument is what is perceived to be the subjectivity of choice and method of weighting the included components, and of the sensitivity of the index to these choices and weights. A second criticism raised in the literature is that positive and negative effects in different factors can cancel each other out meaning that important problems may be hidden in a composite indicator. Related to this second criticism is the point that the sustainability problem is a complex one and the question must be asked whether it is reasonable to attempt to capture the answer to the question “are we behaving sustainably?” in a single number.

On the basis of this type of argument, the UK proposal stated in DETR (1998b) is to choose a set of individual indicators over a composite indicator. The question of composite indicators is raised in States of Jersey (1998) in considering the specific example of an Index of Sustainable Economic Welfare, as proposed by Daly and Cobb (1989). States of Jersey (1998, p.15) note that the ISEW “has attracted broad public endorsement although there remain technical reservations which need to be

¹¹ Note, therefore, that monetary measures of the sustainability gap would not give a measure of environmental damage, only of repairing that damage.

refined". However it should be said that Jersey does not appear to rule out composite indicators *in favour of* individual indicators, rather that the idea of composite indicators is simply not yet taken forward.

While the points made in criticism of composite indicators are certainly true, it is not clear that this should rule out their use in favour of individual indicators. One point is that the argument of subjectivity in the choice and weighting of components applies equally to the decision to have a set of individual indicators unless all possible factors are included in the set. This is because choosing a set of individual indicators implicitly involves attaching zero weight to any factors not included. More generally, I would argue that the question of individual and/or composite indicators is not being addressed in the best way. If this problem is considered from the perspective of the two types/interpretations of sustainability identified in Section 2.2, global sustainability and quality of life in any one country, then both individual and composite indicators become relevant depending on the sustainability problem in question.

In terms of global sustainability - where I have argued that this involves economic progress/development under a set of binding sustainability constraints, *all* of which must hold - the criticisms made above of composite indicators are crucially important. In section 2.2 I explain that if one of the constraints necessary for sustainability is broken, then the system will become unsustainable. If this is the case then missing out something important, under-weighting a component, and/or cancelling effects could lead to the mistaken conclusion that current behaviour is sustainable when in fact it is unsustainable because a binding constraint may be violated. This, however, will also be true of sets of individual indicators if the set is incomplete. Indeed the question could be raised as to whether an exhaustive list of constraints necessary for global sustainability is possible when knowledge is incomplete as to how the global system functions (i.e. we have incomplete knowledge on the working of ecosystems etc). However the argument I am making here is that in the case of global sustainability individual indicators are *necessary* to check that *none* of the constraints on behaviour necessary to prevent the risk of

system collapse is being violated¹². (Of course this must be qualified in that such constraints can only be based on current knowledge as to how the global system functions.)

However if the sustainability being addressed relates to the quality of life in any one economy, the situation is less clear cut. In this case *both* individual and composite indicators are useful, and the criticisms made of composite indicators are less valid than in the case of global sustainability. One criticism that is often made is the subjectivity involved in choosing and weighting components for any welfare index *is* an important point. There are two aspects to this. First, how to get people to reveal their true subjective preference. Second, how to aggregate these preferences. (I return to both these issues later on.) This means that in practice any social welfare function is to some degree a somewhat arbitrary one, in as much as any political process rarely identifies a unique solution that would be unanimously acceptable. Moreover, a social welfare function that is acceptable in one country is unlikely to be ideal for any other. For one thing, the political process differs across countries (even across democracies) and this will affect *how* the social welfare function is determined. Secondly, even in countries with similar political processes preferences will vary with things like culture, religious beliefs etc.

However the reality is that policymakers *have* to make welfare decisions for the country or region they are responsible for, and this involves making decisions on trade-offs between different factors. This implies that in making any decision policymakers *implicitly* use a social welfare function, in that they will take into account a number of factors which will be traded off against one another depending on the importance, or weight, they attach to each one¹³. Therefore it can be argued that the explicit statement of a composite indicator(s) is simply focussing on

¹² One possibility to monitor system sustainability using a composite indicator/social welfare function would be if a non-linear function were used. For example if emissions of some pollutant, p_x , cannot not exceed value p_x^* if the system is to remain sustainable, as p_x approaches value p_x^* , the value of the social welfare function will fall dramatically.

¹³ However, in reality, due to the nature of the political process in any country, the implicit social welfare function used by policymakers is likely to be variable, in terms of what variables are included and the weights attached here. Moreover, policymakers may not wish to make these trade-offs explicit.

something policymakers have to come to terms with every day, and that rejection of composite indicators on the grounds of subjectivity implies a failure to recognise this point.

Moreover, it should be noted that environmental goods (or ‘bads’, in the case of pollution) often tend to have the characteristics of *public goods*, and it is difficult to derive an efficient method for determining the ‘right’ level of public goods¹⁴. Determining the optimal level for a pollutant, for example, is complicated by information problems regarding the true (social) marginal cost of pollution as compared to the marginal benefit arising from the polluting activity. The situation is further complicated by the fact that in reality a large number of environmental factors are often involved. This means a situation with *multiple* public goods. However, if the country is a democracy, the population elects governments to make welfare judgements and provide public goods on their behalf. The political process can reveal weights to represent what people think are the marginal trade-offs involved between different public goods to report, in the form of an index or welfare function, a composite public good: the quality of life.

Determination of a welfare function as an indicator of progress, using components and weightings relevant to the preferences of the people living in the economy in question (and this will vary from country to country), would then seem to be a perfectly valid and useful exercise. In cases like that of Jersey, where a consensual process has been used to determine what is important to the people of Jersey regarding their quality of life, such an exercise to establish a welfare function would seem, in principle, possible. (Though attention should be drawn to the theoretical problems inherent in aggregating individual preferences to get a social welfare function, as proven in what is known as Arrow’s Impossibility Theorem¹⁵.)

¹⁴ It can of course be argued that not all environmental goods have the characteristics of public goods, and that markets may be capable of allocating efficient levels of some environmental goods, in particular many natural resources. The point is that it is necessary to recognise the distinction between cases of ‘missing markets’ (e.g. pollution) and cases where markets *do* exist but might be imperfect (e.g. finite natural resources such as oil). The problem in the second case is that there might be market failure so market prices might not be the ‘right’ prices for sustainable supply.

¹⁵ Arrow (1951) identified a number of conditions that one could reasonably expect to be met by a collective ordering of preferences. However his ‘Impossibility Theorem’ demonstrates how there is no

In the sustainability literature, the aforementioned idea of an Index of Sustainable Economic Welfare (ISEW), also known as a ‘genuine progress indicator’ (GPI), is the best known suggestion for such a welfare function. However it should be noted that none of the ISEW indices compiled to date use data on preferences elicited through a consensual process such as that of Jersey (see section 6.1 below for a fuller discussion of work on ISEW indices). The question of sensitivity to what components are included and assumptions are made is an important one (see Perman *et al* 1999, pp.509-511, on how the gap between GDP and an ISEW may collapse if certain components are removed). However, this question of sensitivity does not rule out the possibility of using composite indicators like an ISEW, provided that sensitivity analysis is possible so as to explore the impact of different definitions of an ISEW (particularly in terms of the weights attached to different components).

However, even in considering the case of quality of life, the argument that important factors can get hidden in a composite indicator remains valid. For this reason it would seem important to have a set of indicators for all the individual factors which impact on the quality of life, and that these be monitored as well as the composite indicator. An important reason for employing both composite and individual indicators is, as will be discussed below (in section 7), that many individual factors may impact on the quality of life, meaning that the set of individual indicators may be large. The appeal of a composite indicator is that it aids comprehension and is likely to be more digestible and less overwhelming than a large series of individual indicators. These are important considerations to those hoping to inform and involve a wider audience in the question of sustainability, which requires changes in the behaviour of individuals. Moreover, it can be argued that an index would force the *opportunity cost* (including the environmental opportunity cost) of any decision to be taken into account. As argued above, the weights with which different components enter the index represent the marginal trade-off between different factors that affect the quality of life/quality of the environment, which is not the case if a small number of factors are examined individually. These advantages of using composite indicators

procedure by which to transpose individual preferences into a collective preference ordering that

are set against the risk of under-informing, but this problem is countered if individual indicators of key factors thought to impact on the quality of life in the economy in question are also available.

Another point that should be made is that while the informational advantages of an index/composite indicator in terms of comprehension are clear, there may be problems if the purpose of the indicator is to *monitor* the government in question. This is because, as noted above, different countries may attach quite different weights to different factors, which may be a source of tension if a country is perceived as attaching too much/too little weight to what others regard as the ‘wrong’ things. If the purpose of having a composite indicator/index is to monitor government performance relative to that of other governments, this is likely to involve a trade-off between having an index which properly reflects the preferences of the country in question or an index which is internationally comparable. In short, the benefits of having an internationally comparable index would have to be assessed against the costs of losing components/weightings that reflect country-specific preferences.

6. Composite Indicators/Indices

While policy proposals on sustainability and sustainability indicators have largely focussed on sets of individual indicators, there have been some practical developments in the area of composite indicators. Two types of composite indicator in particular seem to have gained the most attention: the concepts of an Index of Sustainable Economic Welfare (ISEW) and Ecological Footprints. In this section I consider each of these in turn, in terms of what appear to be the two main issues in developing a composite indicator or index:

1. Choosing components/variables for inclusion in the index.
2. How the components are aggregated to form the index/weighting of components.

satisfies all these conditions. To date no one has found a satisfactory way to overcome this problem.

6.1 The Index of Sustainable Economic Welfare (ISEW)

Daly & Cobb (1989) seem to be the first source of the ISEW concept. Initially calculated using US data, it is the most frequently cited measure in discussions of composite indicators of sustainability. The ISEW actually appears to be an attempt to measure a ‘Green GDP’, or ‘sustainable national income’: the weight each component carries is the absolute monetary value assigned to it, and the index is calculated by summing over the positive and negative values of the components. The first problem therefore is clearly the one that I have highlighted in the introduction to this chapter as the widely accepted reason why such measurement is not a practical option. This is the problem of valuing what Daly & Cobb (1989, p.416) themselves describe as “inherently immeasurable” factors such as many natural/environmental resources¹⁶. In explaining this measurement problem, Daly & Cobb (1989) ask the question of how one would go about imputing the cost imposed on future generations by the depletion of natural resources. In the case of environmental damage, they point out that the estimation of costs will always be clouded by the high degree of uncertainty surrounding the precise physical effects of human actions. This all makes the suggestion of the ISEW as a composite indicator to form part of a system of satellite accounts somewhat paradoxical, since it runs into the very problem that such a system is trying to overcome.

A second problem with Daly & Cobb’s (1989) ISEW is that the choice of components included in the index seems to be wholly that of the authors, and they spend twelve pages justifying their selection. In section 5 above I argue that if the index is intended as a measure of quality of life or some type of welfare function, then the choice of components, and the weights attached to them, should be determined by the preferences of the people whose welfare is in question. There I propose that this could be determined either by some revealed preference technique or through the political process, or both. On this criterion, the choice of components

¹⁶ It should be noted that Daly & Cobb (1989, p.416) do draw to attention to this measurement problem and calculate an alternative ISEW, which does not include those factors that are regarded as “inherently immeasurable”.

in the ISEW is somewhat arbitrary and highly questionable, as are the weights assigned, given the accepted measurement problem. Therefore, I would argue that while the idea of an ISEW as a social welfare function is acceptable in principle, the methodology employed by Daly & Cobb (1989) in choosing and weighting components is unacceptable.

What then of Daly & Cobb's (1989) ISEW from the perspective of recognising environmental limits on economic activity? Here there is a much more fundamental problem: again, I argue in section 5 above that where sustainability requires that activity take place within environmental limits (leading to 'sustainability constraints') it is necessary to construct individual indicators in order to monitor that none of these constraints are broken. I have argued that the conventional criticisms of composite indicators in general do tend to hold in this case. One of the points I make is that the subjective nature of 'quality of life' or welfare, and the possibility of trade-offs, mean that it is reasonable to construct an index, but one based on the preferences of those people whose quality of life is in question. However, this is not the case for environmental limits if there is a risk of system collapse in the event of even one limit being exceeded. More generally, I have argued that the whole concept of using an index to monitor that economic activity takes place within environmental limits is questionable because of the likelihood of cancelling effects between positive and negative factors, meaning that important problems may be hidden and constraints violated without warning.

A number of ISEW indices have been compiled in the ten years since Daly & Cobb (1989) originated the concept. Cobb, Halstead and Rowe (1995) develop a version of the ISEW for the US which they called the Genuine Progress Indicator (GPI), and over the last decade there have been a number of ISEW/GPI indices compiled for a range of countries. For example, indices have been constructed for the UK (Jackson and Marks, 1994), Germany (Diefenbacher, 1994), Sweden (Jackson and Stynne, 1996), Australia (Hamilton & Saddler, 1997) and Scotland (Moffatt & Wilson, 1994, and Hanley *et al*, 1999). All of these indices build on the original Cobb and Daly index, but with various refinements and developments. However, all of the criticisms

and debate that have taken place during this process have largely focussed on what is included in the index, with no apparent recognition or acknowledgement of the points I have raised here.

This leads to the major criticism of the general ISEW methodology as being totally ad hoc, basically using whatever information is available on whatever the authors in question deem appropriate for inclusion in their index. In section 5 above, I propose that an index of sustainable economic welfare would constitute a useful and acceptable practical example of a social welfare function in measuring (and trying to maximise) the quality of life enjoyed in a given country or region¹⁷. However, this is not how ISEW indices have developed over the ten-year period since Cobb and Daly in 1989. In particular, these indices have failed to tackle the problem that the welfare of the people in any country/region depends on the preferences of those people.

The work to date on the ISEW concept should not, however, be dismissed because it does provide a useful starting point for thinking about developing an index that could act as a sustainable economic welfare function, or a quality of life index. The fact that most of the ISEW debate has been over what should be included suggests that there is no universally correct answer. The best solution to this would seem to be to let the people whose quality of life is in question, and/or the policymakers they have elected to represent them, decide what should be included in the index, and to let them determine the weighting attached to each component. Of course, such an approach carries with it problems of its own:

1. Eliciting people's true preferences: what I am suggesting is a *revealed preference* approach, but there are likely to be problems in eliciting people's true preferences and rankings.
2. Even if true preferences and rankings can be elicited, next there is the problem of aggregating across individual revealed preferences as identified in Arrow's Impossibility Theorem (see Section 5 above).

However, even if these problems cannot be fully overcome, the resulting index would be preferable to one whose components have been chosen by individual authors, and weighted solely according to acceptance of monetary valuations of the included components, many of which are factors for which no markets or prices exist.

There is another problem though. Since there do not appear to have been many past attempts to build a sustainability index of the type proposed here, the more recent literature does not offer a great deal in the way of practical guidance. However there has been some useful work done, in particular by Ralph L. Keeney in the area of 'Decision Analysis'.

Keeney (1974) specifically addresses the issue of quality of life in the context of environmental problems, identifying many of the arguments put forward here. First of all, as I have discussed above, Keeney (1974) points out that there tends to be no consensus on what environmental objectives should be, and that there are usually multiple objectives to be considered, meaning that trade-offs are inevitable. He argues that usually these trade-offs will be between economic and material development and environmental quality, but draws attention to the fact that both economic/material development and environmental quality impact on people's quality of life. This will be different for different individuals, which implies a need to integrate individual attitudes to yield a quality of life indicator for societies where such decisions have to be made. Keeney (1974) also draws attention to the fact that there is added complexity because of the time-scales and inherent uncertainties involved in environmental decision-making.

Another important factor is that there may be many agencies involved in environmental decision-making, which may lead to ambiguity as to who is responsible for making decisions. For example, in the Jersey case, as well as the local government (the States of Jersey), we also have to consider international agreements,

¹⁷ Subject to the problems inherent in any attempt to build a social welfare function, as noted in

and what Jersey's position is when the UK negotiates agreements on its behalf etc. Similarly, in the UK itself, a significant degree of responsibility for setting and achieving environmental objectives has been devolved to the English regional authorities, the National Assembly for Wales and the Scottish Parliament. However, regional outcomes will influence the environmental performance of the UK as a whole, and this is constrained where the UK has made commitments at the international level.

A particular reason why Keeney's (1974) work seems useful is that he recognises the subjective nature of people's preferences with regard to quality of life, but argues that there is a need to attempt to formalise this aspect of the problem. He makes the point that quality of life tends to be considered only superficially, largely because of the complexity of the task – which is perhaps why there has not been a great deal of work in the area since. However, he goes on to argue that quality of life is fundamental in environmental problems, and *must* therefore be considered.

Another reason why Keeney's work is useful in terms of the problem being addressed here is the practical guidance his approach offers. Keeney (1974) describes the decision analysis approach to addressing environmental problems in the context of quality of life. Just as I have argued in this chapter, he regards the first step as specifying objectives through some process of generating and assessing alternative objectives, by identifying the possible consequences of each alternative. Once objectives have been specified, the next step that Keeney's (1974) approach takes is to assess the preferences of the people whose quality of life is in question, or those of the policymakers representing them, with the aim of building a collective utility function. The problems with this process, which have already been identified above, are also acknowledged and discussed by Keeney (1974). While the theoretical problem of aggregating individual preferences to give a collective utility or welfare function, as stated by Arrow (1951), remains unresolved, later work by Keeney *et al* (1990) offers guidance, drawing on a practical exercise conducted with members of the German public, on eliciting public values and preferences. The final stage of the

approach outlined in Keeney (1974) involves sensitivity analysis of the results of the preference elicitation exercise, which I have argued here to be important in light of the subjectivity problem associated with the use of indices.

The conclusion that I draw from this section, then, is that useful work *can* be done on building a composite indicator where the sustainability concern in question is that of the quality of life. This would involve building on the ISEW concept by introducing components and weights determined through some revealed preference approach.

6.2 Ecological Footprints

Another type of composite indicator which has generated considerable interest is the concept of an ecological footprint, which is introduced by Wackernagel & Rees (1996, p.9) in the following way:

Ecological footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area. Typical questions we can ask with this tool include: how dependent is our study population on resource imports from “elsewhere” and on the waste assimilation capacity of the global commons?

Basically Wackernagel & Rees (1996) start from the assumption that every category of energy and material consumption and waste discharge requires the productive or absorptive capacity of a finite area of land or water. They then sum what they calculate to be the land requirements for all categories of consumption and waste discharge by a defined population, and this gives a figure for the ecological footprint of that population, which may not coincide with what is available within the population’s home region. Therefore the ecological footprint of a specified population or economy is defined as the area of ecologically productive land (including land embodied in imports) required on a continuous basis to support consumption. Moreover, the ecological footprint of a given population is the land area needed *exclusively* by that population: flows and capacities used by one

population are not available for use by others. This basically implies that one region's resource-based consumption can only be increased through a reduction elsewhere, given a fixed global area of ecologically productive land.

Van den Bergh & Verbruggen (1999, p.62) point out that “the [ecological footprint] concept and indicator seems to be accepted almost without any critique by many scientists and policy makers, and especially by environmental organisations”¹⁸. However, there are several important points that should be recognised in considering Wackernagel & Rees' (1996) ecological footprint approach. To begin with, there are a number of technical points, the most important being what seems to be the arbitrary nature of assumptions involved in the whole approach. First of all, the assumption that land area is all that is required to accommodate any type of energy and/or material consumption¹⁹. Wackernagel & Rees (1996) state that they also consider water (although how this is the case is not clear from their calculations²⁰). However even if this were the case it does not seem adequate, certainly not in the case of waste assimilation (for example, how does the problem of depletion of the ozone layer enter into the ecological footprint calculation?). Van der Bergh & Verbruggen (1999) also question the method of using land-use to account for all consumption activities, particularly in the case of energy-use. They note that (van der Bergh & Verbruggen, 1999, p.65) “[T]he land appropriated by fossil energy use makes up more than 50% of the ecological footprint estimate for most developed countries”. In ecological footprint calculations CO₂ emissions are only assimilated by the environment through ‘carbon sink’ land in the form of forest land. However this is not the only way to compensate for CO₂ emissions, but it is a very land-intensive one, a point that I shall return to below.

¹⁸ Van den Bergh & Verbruggen (1999) detail some examples of the wide acceptance of the ecological footprint concept and indicator, but note that, beside their own, they have only come across two critical evaluations of ecological footprints.

¹⁹ It is important to note van den Bergh & Verbruggen's (1999) point that the ecological footprint denotes *hypothetical* land area required to support consumption, not actual land area required (which is why it is possible to have an global ecological footprint that exceeds the world's total available land area).

²⁰ In a later paper – Wackernagel *et al* (1999, p.7) – water is introduced in terms of “productive sea”, measured in hectares.

Even if the assumption that all consumption can be accounted for by land appropriated is accepted, a second problem lies in how the land requirement for a given consumption activity is calculated. For example one of the calculations in Wackernagel & Rees (1996) is the ecological footprint of commuting to work by bicycle. The land requirement for this activity is calculated using the assumption that all the energy required for making the trip is obtained from breakfast cereals. Therefore it is the land required to produce the necessary cereal that is actually calculated. However this seems to be a very arbitrary assumption regarding the source of energy: even if the assumption that all the energy required for the morning cycle to work *is* obtained from cereals is accepted (and even this is questionable), what about the ride home?

Van den Bergh & Verbruggen (1999) raise some interesting points on the land-use issue. One is that the ecological footprint does not distinguish between sustainable and unsustainable use of land. They argue that an implication of this point is that intensive use of land in the agriculture sector translates into only a small contribution to the ecological footprint but that such activity is usually associated with high environmental pressure, for example through the use of pesticides and fertilisers. This is likely to be an especially important point for an economy like Jersey, which has highlighted the agriculture sector as a main source of the Island's environmental problems. Another important point made by van den Bergh & Verbruggen (1999) is that land-use is only associated with single functions by the ecological footprint, and they argue that the fact that multiple-use associated with land is neglected will bias footprint calculations upwards.

Leaving these problems aside – i.e. even if we accept the type of assumptions made for calculating the ecological footprint of an individual consumption activity – another problem arises as we move up to the level of the footprint for *all* the consumption activities in a given region or economy. Wackernagel & Rees (1996, p.61) acknowledge that in practice “attempting to include all consumption items, waste types and ecosystem functions in the estimate would lead to intractable information and data-processing problems”, and therefore use a “simplified

approach”. This is of course not unreasonable; simplifying assumptions have to be made in any modelling exercise. Where the problem arises, just as in the ISEW calculations, is in the arbitrary choice of what is included. For example, in calculating the ecological footprint of the Netherlands, Wackernagel & Rees (1996, p.95) choose only four “important” consumption categories: built-up land, food, forest products, and fossil energy. The question immediately arises of why these four? No justification for this choice is given. Even if we assume that this choice would be considered reasonable in the case of the Netherlands (and again this would be a questionable assumption), it is doubtful that the same four consumption categories would be considered the four most important in other countries. This is an important point: one of the reasons why the ecological footprint concept is considered potentially useful is for purposes of international comparison. However, as I have argued above (in section 5) an internationally comparable index would have to have common components for all countries.

This brings us back to a point made above: in the case of environmental limits necessary for system sustainability, a composite indicator is not really a suitable tool. I have argued that if something important is left out, the misleading impression may be given that an economy is sustainable in terms of acting within environmental limits when in fact it is not. And so, once again, the conclusion that I have stated in section 5 applies: this is that in the case of environmental limits, where breaching (any of) these limits will mean a risk of system collapse, it is necessary to monitor a set of individual indicators.

Therefore, there is a problem over what consumption activities are included in the aggregate ecological footprint – i.e. the choice of components. However, van den Bergh & Verbruggen (1999) also express concern over the other key problem that I identify in Section 5 concerning composite indicators: how components are weighted. They question the use of physical consumption-land-use conversion factors in the ecological footprint calculation function as implicit weights in both conversion *and* aggregation, pointing out that while the physical weights used may be consistent with ecological principles and thermodynamic laws, they do not

necessarily correspond to *social* weights. This means that changes in relative scarcity over time and variation over space are not reflected in the ecological footprint measure. Van den Bergh & Verbruggen (1999) argue that this problem is magnified by a fixed weighting scheme, which means that a fixed rate of substitution is assumed between different categories of environmental pressure. They further argue that some categories receive identical weights even though they have distinctly different environmental impacts. In conclusion they state that all these problems compound to render the ecological footprint a questionable tool for social decision making, such as ranking policy options.

There are a number of further criticisms that an economist would level at Wackernagel and Rees' ecological footprints. First of all, there is a very basic problem in that the approach appears to have a universal fixed coefficients view of all production relationships. This is an unreasonable assumption (and one that I address further below).

Secondly, the question arises of what ecological footprint calculations actually tell us. Unless a *global* footprint were calculated (which, judging by Wackernagel and Rees' own comments, would be a virtually impossible task, given the data processing and information requirements) the ecological footprint does not seem to tell us much about sustainability. Ecological footprints for a given individual country or region merely indicate the importation requirements to facilitate that country or region's current consumption. We do not know how this affects the sustainability of the global environment without information on production and/or resource surpluses in the rest of the world²¹.

Thus it seems that the idea of ecological footprints is built on some premise of there being an inequitable distribution of resource-use and consumption in the world – i.e. some countries/regions in the world are consuming more than their fair share of the world's resources. This may be a very reasonable point of view, but without

²¹ Van den Bergh & Verbruggen (1999) also make the point that regional and national, or economic, boundaries are of a geo-political and cultural nature and have no environmental meaning, rendering regional/national ecological footprints as somewhat arbitrary.

information on the tastes and preferences of the populations of all countries and regions in the world – i.e. what they would prefer to consume – this cannot simply be assumed. An approach to sustainability built on this premise misses the point, well known to economists as the basis for trade, that different countries choose to use the resources available to them in order to maximise their own consumption. This means that each country will specialise in production of the consumption goods they are most efficient at producing, and use trade to obtain what other consumption is required (the principle of comparative advantage). In other words, we cannot simply assume that if a country has a small ecological footprint, this is because other countries are somehow misappropriating resources away from it. Even more fundamentally, basic Heckscher-Ohlin trade theory tells us that if we take two factors of production, for example land and labour, a land-intensive country will export land-intensive products and import labour-intensive products. This is not even primarily about preferences. Rather, it is simply about differences in factor endowments.

My argument, therefore, is that while it may well be the case that the global distribution of resources and consumption is in fact an inequitable one, the *ecological footprint* cannot be regarded as an indicator of the equity of this distribution. The basis of this argument is that a footprint calculation does not give attention to factors like differing preferences, or to the fact that ecological differences between countries are likely to provide an opportunity for gains from trade based on the principle of comparative advantage.

This leads me to consider another premise which seems to underlie Wackernagel & Rees's ecological footprints, and one which is also identified by van den Bergh & Verbruggen (1999), that of a preference for *autarky*. On Rees' own web-page he argues the need for "increasing regional self-reliance", and in Wackernagel and Rees (1997, p.21) the statement is made that "A shift [is needed] from the present emphasis on global integration and inter-regional dependence toward greater regional autonomy and self-reliance". However it is difficult to see how this would reduce the

size of ecological footprints; it would merely mean more domestic production²². The necessary requirement for a reduced ecological footprint is reduced *consumption*, wherever in the world the resource and production base of this consumption is located.

Laying aside the doubts that I have expressed over what useful purpose lies in calculating any type of ecological footprint, other than a global one, something can be said about finding a better method of calculation. Suppose that the energy and land inputs required directly and indirectly to support each unit of final demand in a particular economy can be separately identified (for example using the attribution methodology that I adopt for pollution generation in Chapter 7). Then, if all production inputs and pollution outputs can be converted into land requirements, country-specific coefficients for the land-use required to support consumption could be calculated in an appropriate system-wide model. One criticism that I have made with regard to Wackernagel and Rees's (1996) method is that there seems to be an assumption of universal fixed coefficients. However production and consumption technology are known to vary across different types of activities and across space. (For example, in Chapter 6 of this dissertation, I report on an exercise to assess the added precision gained from estimating and using region-specific energy-use and pollution generation coefficients for the target economy of Jersey.) Using system-wide accounting and modelling techniques would not only allow the identification of economy-specific coefficients, but those coefficients could also be made endogenous to the system, with the implication that they would react to changes elsewhere in the system.

It is also important to note that the ecological footprint is, at best, simply an *indicator* of whether the consumption activities of the population/economy in question are exceeding the carrying capacity of home region. In other words, the ecological footprint is simply a *description*, and a somewhat limited one given all the arguments above, of whether current consumption activities (i.e. for a given point in time) are

²² Moreover, it is difficult to see how this regional self-reliance could ever materialise, since it is difficult to think of a region or country in the world that is a self-contained ecosystem capable of supporting life in isolation.

consistent with the sustainability objective(s) reflected by this indicator. However, if we want to understand *why* a given population/economy has the size of footprint it does and the impact of changes in the value of the footprint over time, it would seem necessary to adopt a modelling approach.

Van den Bergh & Verbruggen (1999) also argue that a modelling approach is required rather than simply an accounting procedure if we require the type of information that the ecological footprint claims to provide. They point out that the ecological footprint “is not consistent with the marginal cost thinking of economics” (p65), which makes it “unnecessarily unrealistic from an economic perspective”. For example, in the case of CO₂ assimilation, they argue that, even if devoting land to forests for this purpose were the cheapest option, this is unlikely to remain the case as more land is (re)-forested because the option will become more expensive as suitable land becomes increasingly scarce. In terms of the wider problem of sustainable energy-use, van den Bergh & Verbruggen (1999) make the point that the ecological footprint does not capture the effect of substitution away from fuels that are becoming expensive, or energy intensive activities, to cheaper alternative fuels or less energy intensive activities. Again, this is because the ecological footprint calculation does not involve modelling of relationships in the system.

My conclusion, therefore, is that the use of *system-wide* modelling would allow more useful and far less arbitrary calculation of an ecological footprint. First of all, this would allow a better reflection of consumption and production relationships in the target economy than is implied by Wackernagel & Rees’s (1996) fixed universal coefficients perspective. Secondly, if this indicator is to be used to determine the ecological impact of any change in economic activity (for example, Wackernagel & Rees’s, 1997, recommendation for a reduction in consumption of imports) a simple accounting approach is not suitable. There is a crucial distinction between the analysis of *average* consumption behaviour at a given point in time that is possible in an accounting framework, and analysis of *marginal* changes in behaviour that is only possible in a modelling framework. However, there would clearly be a considerable

problem in that modelling input would also be required for countries other than the target economy in order to determine the resource contents of all imports.

In the case of Jersey, an ecological footprint *could* be calculated using this type of system-wide approach, since a model of the economic-environmental system of the island is being constructed anyway. Additional information would be required for the conversion of the production inputs and pollution outputs necessary to support consumption into land requirements. However it may be possible to draw upon existing work by Barrett (unpublished), who has constructed an ecological footprint for Guernsey, one of the other Channel Islands, for guidance on conversion factors etc. Another useful starting point is the work of Bicknell *et al* (1998) on calculating an ecological footprint for New Zealand using input-output (IO) methodology (the most common and straightforward type of general equilibrium modelling). This study would appear to constitute a significant improvement on previous footprint methodology, in that it is the first to offer systematic measurement in a standardised accounting framework, using a basic system-wide modelling approach of the type suggested above. There are, however, significant limitations associated with employing IO methodology in general (not just in the case of footprint calculations), that are recognised by Bicknell *et al* (1998) and explained in relation to their study. However, this is not an area that I intend to develop in the present study.

7. Sets Of Individual Indicators

Despite the interest in developing composite indicators, having a set of individual indicators is the most common approach to monitoring progress towards sustainability. As noted above, the UK government has chosen to use a set of individual indicators with the use of composite indicators limited to things like the Global Warming Potential (GWP) index²³, wherein the components and weights have been determined by independent scientific studies. Jersey's initial proposals (States of Jersey, 1998) are also limited to individual indicators, though they have also expressed an interest in the less controversial GWP index. Proposals for

²³ The GWP Index is introduced to this study and discussed in more detail in Chapter 6.

monitoring progress towards sustainable development in Ireland also only include a set of individual indicators²⁴ (Environmental Protection Agency, Ireland, 1999).

7.1 Number Of Indicators

The question of the correct number of (individual) sustainability indicators in the proposed set for any given country or region would appear to have been the subject of much debate and consideration. Both the UK (DETR, 1998b) and Jersey (States of Jersey, 1998) consultation documents discuss this issue and a number of suggestions are raised. For example, the consensus seems to be that a country needs a ‘full’ set of indicators - the UN Commission on Sustainable Development’s recommendation was for 140 indicators, and the UK has around 150 in its ‘core’ set – which, if possible, should be internationally comparable. There also appears to be agreement that there should also be a ‘headline’ set of key indicators from the full set to give an overview of progress and to focus attention - DETR (1998b, paragraph 3.3) states that “a general view is that no more than 10 indicators would be ideal”.

However I would argue that this focus on finding the correct number of indicators seems an odd one. One important point is that it runs into the problem raised in the same consultation documents regarding subjectivity over what is included. If too much attention is placed on having some specific number of indicators, surely this increases the chance that indicators of important factors will be left out (thereby implicitly attaching a zero weight to the corresponding objective)? The correct number of indicators would seem to be the number needed to address the problem at hand, given the structure of the economy in question, and under the constraints of technical feasibility and costs of collection.

Once again, I would argue that the basis from which to address this question would seem to be the type of sustainability being considered: global sustainability or quality of life within the economy in question. If global sustainability requires that a set of constraints be met, with the violation of any one meaning that activity is

²⁴ Note that the Irish EPA’s document only includes discussion of *environmental* indicators.

unsustainable, then there is no choice over the number of indicators. There must be an indicator for each relevant factor (for each constraint that must be met). The idea of a ‘headline’ set to focus public attention does remain a valid one, as the full set may contain too much information (though even this is questionable if each element is considered critical for sustainability). However, the *policymaker* would still have to give equal attention to all constraints and their relevant indicators, and the appropriate headline set will depend on the geographic area (country/region) in question.

If it is felt that there really must be a limit to the size of the list, even for the policymaker, surely focus must be on those factors *most likely to go wrong* (i.e. what constraints are most likely to be broken). I would argue that this would seem to be a more appropriate focus than the most ‘important’ in terms of preferences or scientific opinion on what is most likely to cause system collapse. For example, depletion of finite resources such as fossil fuels is regarded as one of the most important factors in the sustainability debate, since the use of fossil fuels is (currently) necessary to facilitate most economic activity (directly or indirectly). However it may be argued that the market mechanism will prevent depletion reaching a critical level: as, for example, oil supplies become more scarce, and exploration and/or extraction costs rise, this will cause prices to rise, causing demand to contract and the rate of depletion to fall. If this is the case, indicators relating to depletion of such resources would not require so much attention as indicators of what are perceived as less important factors, but ones for which the market mechanism may not be adequate, or for which markets do not exist. The issue is one of information. The price mechanism could be expected to signal depletion of a marketed resource like oil, but not factors such as ozone depletion.

On the other hand, if sustainability is being considered in terms of maintaining quality of life, the correct number of indicators will depend on the number of factors thought to impact on the quality of life in the country or region in question. And, again, the question of tastes and preferences in that country/region will be important in choosing and attaching weights to different factors, just as with a composite

indicator. The difference is that the ‘weights’ in a set of individual indicators will relate to the choice over what is included and what is left out. The point over having a ‘headline’ set of indicators that a wider audience can take on board remains a relevant one. However (in light of the arguments I have made in Sections 3 and 4 on the UK proposals) in the case of both global sustainability and quality of life indicators it is important to pick a *sensible* core of ‘headline’ indicators. That is, one which addresses the stated objectives properly and evenly.

7.2 Types Of Indicator

A common theme in the literature on sustainability indicators is classification of indicators according to type. The most common classification recommended is the OECD approach of *pressure-state-response*. The UK (DETR, 1997) explains that its approach is based on this classification, which is considered useful because it allows sustainability issues to be addressed in a systematic manner. The idea is that human activity exerts *pressure* on the environment within which it takes place, which affects the *state* of the environment in terms of quantity and quality of natural capital. However society can *respond* through changes in its behaviour (e.g. via policy) to affect the *pressures* on, and the *state* of, the environment.

Such classification would certainly seem to be useful, as it will focus attention on the interactions and interdependencies within the economy, the environment and between the economy and the environment, or more specifically on what Azar *et al* (1996) refers to as “the causal chain” (p90). Azar *et al* (1996) argue that indicators that focus early in the causal chain are important where there may be long time delays between a given activity and the corresponding environmental effect. They also make the point that the complexity of ecosystems makes it difficult, if not impossible, to predict all possible effects of an activity. The analysis results in Azar *et al* (1996) coming up with their own classification of indicators: societal activity indicators, environmental pressure indicators, and environmental quality indicators. These largely encompass the same type of concerns as the pressure-state-response concept, just in a slightly different way.

The point I am making here is not a criticism of having these different classifications of indicator, rather I am concerned that discussion and debate over classifying different indicators (on which subject the UK's (DETR, 1997) theoretical discussion goes into in some detail) will cloud the real issues in question. Environmental economics uses the classification of *stocks* and *flows* when looking at resource use and pollution, which would seem to be the simplest and most instructive way of considering what indicators are required.

Suppose we think of the earth (the environment) as a closed materials system with stocks of natural capital. Then, resource extractions are flows to the economy from these environmental stocks. The corollary of this is pollution/waste generation involving flows from economic activity back to the environment, which has a capacity to carry some stock of pollution/waste. In thinking about sustainability we need to consider both flows and stocks together. The stock levels of both resources and pollution in the environment affect the sustainable flow levels: the marginal cost of resource and pollution/waste flows depends on the level of existing stocks of resources and pollution/waste in the environment²⁵. Stock levels of resources and waste/pollution in the environment may also change for reasons other than flows from and to the environment. Particularly, there may be changes as a result of natural regeneration (e.g. renewable resources, biodegradable waste/pollution) or through human effort (e.g. new discoveries that change known stock levels in the case of resources, and clean-up efforts to repair environmental damage). Understanding the stock and flow relationships in the economy-environment nexus, along with identifying chains of causality, will allow the best type of indicators to be selected for different problems.

Another important point is that the pressure-state-response concept is rather limited in that it focuses simply on the effect of economic activity on the environment, and on changes in that activity initiated by, for example, policy reaction to environmental

²⁵ Anderson & Francois (1997) point out that the *marginal utility* people get from improvements in the cleanliness of the environment also depends on the existing stocks of pollutants. They argue that this

changes, in the case of response. However sustainability is about more than this and an important factor which seems most neglected by the pressure-state-response approach, and in all the proposals, is distribution. The state of the environment, the environmental effects of economic activity, and the effects of environmental policies, all have different distributional implications for people living in different circumstances, in different geographical areas etc. Again this raises the basic point that classifications are less important than identifying and understanding the sustainability issues of concern, setting achievable objectives, and finding indicators which best help to monitor progress towards those objectives, whatever type or classification of indicators these may be.

8. Chapter Summary And Conclusions

8.1 The Problem Of Defining What Is Meant By ‘Sustainability’ And Choosing Sustainability Indicators

One key point that I have identified in my review of the consultation documents on sustainability and proposals for sustainability indicators by the UK and Jersey is the problem of defining what precisely is meant by the idea of sustainability. Both the UK and Jersey seem to be aware of the problems that make measurement of sustainable income, or a ‘Green GDP’, very difficult and of the role of sustainability indicators in managing economic activity in a way that is sustainable. The basic problem seems to arise when it comes to defining what is meant by sustainability. In Section 2 I identify two different types of sustainability concerns²⁶:

- (1) Concern over the sustainability of the global (or local) system of the type identified in ‘the Limits to Growth’ (Meadows *et al*, 1972), which gives rise to binding constraints.

is an important factor in government decision-making over provision of environmental cleanliness (as a public good) and pollution abatement/environmental restoration.

- (2) Concern over the quality of life enjoyed in a given country or region, which implies the possibility of trade-offs according to some social welfare function.

The issue of sustainability for any country involves both of these elements, and the two are inexorably interdependent. However in addressing the two, through setting sustainability objectives, and selecting appropriate indicators and targets to help meet those objectives, it is useful to consider them separately because the type of sustainability concern in question has implications for how it can be addressed. For example, a small regional or national economy is likely to have much more control over sustainability in terms of the quality of life of its inhabitants than it does over questions of global sustainability. Moreover, while international standards and agreements are crucial in addressing problems of global sustainability, concerns over quality of life need to be addressed in a country-specific manner since preferences and tastes over quality of life, and the problems and constraints faced, differ from country to country.

When the different types of sustainability concern are separated in this way, as I have shown in the latter sections of this review, many of the questions as to the appropriate type and number of indicators are resolved by the need to address the relevant issues in a practical manner. Most of the restrictions on how to address the sustainability problem lie in the area of global sustainability (since constraints here are likely to be binding and problems must be addressed on a global scale with multilateral co-operation and co-ordination). However there is more freedom in addressing questions of quality of life, with individual policymakers able to make trade-offs to reflect the preferences of their own people, within the constraints of the economy and of international agreements on global sustainability.

The uncertainty over the whole sustainability question is perhaps what leads individual governments to be somewhat vague in stating sustainability objectives and to seek standards and recommendations as to appropriate sustainability indicators.

²⁶ Note the point made in section 2.2 that the identification of these two types of sustainability concern is intended to provide a framework for addressing sustainability concerns, rather than providing the basis for definitively categorising concerns.

The argument I am making here is that clarification of the different types of sustainability issues, and of the options open to individual governments in addressing them, will allow a more practical approach to addressing sustainability. The approach proposed in the UK and Jersey consultation documents reviewed here involves the use of sustainability indicators to monitor progress towards meeting a set of sustainability objectives that reflect the ultimate goal of sustainable development. In this chapter I have argued that this approach can be improved upon by focussing on the specific type of sustainability concern in question, which would allow more meaningful objectives to be set, and a more practical choice of indicators for monitoring progress towards these objectives.

8.2 The Need To Model Sustainability Indicators In A Computable General Equilibrium (CGE) Framework

The crucial thing that my review of the consultation documents published by the UK and Jersey governments demonstrates is that there is significant policy interest in measuring and tracking the movements of chosen indicators that reflect agreed sustainability objectives. Moreover, as I explain in Chapter 1, following the devolution of much of the responsibility for setting and achieving sustainability objectives, this policy interest is also reflected at the regional level in the UK.

However, I have argued here that one crucial issue has not been addressed in the policy proposals reviewed here, and it is this that motivates the rest of my dissertation. The proposed process of monitoring a set of sustainability indicators is a purely *descriptive* one, where the indicators simply reflect sustainability objectives, and monitoring them simply describes whether or not development is becoming more or less sustainable. What is missing is an *explanation* as to *why* indicators are moving in the observed direction. If, as is widely believed, the current path of development in the economies like the UK and Jersey is in some way unsustainable, this suggests we need to know two things. First, what is causing development to be unsustainable, and secondly, what type of corrective action will get the economy onto a path that is sustainable. In other words, it is necessary to understand what is *causing* changes in

the values of the variables that are considered important for sustainable development – i.e. those variables being represented by the chosen indicators. This would allow identification of what type of activities cause development to be unsustainable, and/or to find out what activities, such as policy, will cause development to become sustainable. Therefore what is required is knowledge of the *transmission mechanism* linking economic activity to any disturbance to the system, such as policy, and the variables which indicate sustainability. The argument motivating my dissertation is that multi-sectoral general equilibrium modelling provides this transmission mechanism. If I can model the relevant behavioural relationships and interdependencies in the economy-environment system, incorporating the indicator variables as endogenous variables, then it should be possible to capture the sequence of causality between any activity or disturbance and any change in the indicators.

Moreover, in the simply descriptive process of monitoring through observing the movement of indicators, if there is a change in one or more of the indicators it will not be possible to isolate the reason why the change has occurred. Any number of factors may be observed that could have caused the change, but it is not possible to say which was in fact responsible. However in using a model of the system it is possible to isolate individual disturbances, such as the use of policy instruments, in order to determine the effect of that one factor on different individual, or composite, indicators. Moreover, it is important to note that the effect might be different on different indicators. For example, a given disturbance or policy action may cause some indicators to move in the correct direction for sustainability, while causing others to move in the wrong direction because of the nature of the numerous interdependencies and behavioural relationships in the system.

However, there is clearly recognition among the devolved regional authorities of the UK of the need to understand and explain what drives the behaviour of sustainability indicators rather than simply measuring and monitoring their values. The National Assembly for Wales and English Regional Development Agencies are in the process of consulting with the UK Environment Agency on developing appropriate databases and frameworks for measuring and analysing the type of sustainability indicators

identified by the UK. In the case of Scotland, the Scottish Executive has begun an independent consultation process. The Scottish Environmental Accounts Working Group (SEAWG) has been set up in order to consult with local agencies and academics on developing a system of environmental accounts and identifying appropriate composite and individual environmental indicators for Scotland. SEAWG has also identified the need to develop system-wide multi-sectoral empirical frameworks for analysis of economy-environment interaction at the regional level.

One outcome of the regional consultation processes in the UK seems to be an agreement that the first step should be development of regional environmental input-output (IO) accounts. These can be used to link indicators such as the physical use of different types of energy and generation of different types of pollution to individual production and consumption activities. Environmental IO accounts for a given year can also be used for basic multiplier, or *attribution* analyses. Attribution analysis is used to identify things like the average emissions intensities of and total emissions attributable to different types of final consumption demand in that year, taking into account pollution engendered in the domestic production of goods and services. Thus, the construction of environmental IO accounts for the UK regional economies would permit identification and measurement of sustainability indicator variables in terms of the economic variables that are believed to cause movement in their values.

However, such a development is still at the consultation stage in Scotland and the rest of the UK. There is a history of work on developing environmental IO accounts in the UK. The Environmental Accounts Branch of the Office for National Statistics constructed a pilot set of national environmental IO accounts for the UK in 1993 (see Vaze, 1997). However, this exercise has never been repeated. The only attempt to develop an environmental IO system for a UK regional economy is the Scottish system constructed by McNicoll & Blackmore (1993) for Scottish Enterprise (the Scottish regional development agency) at the University of Strathclyde. Some work has been done on developing and updating the Scottish environmental IO framework (see McGregor *et al*, 2001c). There has also been some recent work on constructing a

Welsh environmental IO system. However, all attempts at developing regional environmental IO systems in the UK have been restricted by a lack of region-specific data. This is a problem constructing both the basic tables IO describing the structure of the economy (UK regional IO accounts are only available in the case of Scotland) and the economic accounts recording input/outputs of environmental variables associated with economic activity at the sectoral level.

On the other hand, due to the availability of appropriate region-specific economic *and* environmental data, in this study I can use Jersey as an illustrative example to investigate how the construction of a regional environmental IO system is a useful first step in building a framework to analyse sustainability indicators. I discuss the construction of a region-specific environmental IO system for Jersey (for the year 1998) in Chapters 5 and 6. In Chapter 7 I use the system to conduct some basic accounting, or attribution analyses. This yields some very useful results regarding the size and nature of environmental problems in Jersey as identified by a range of illustrative environmental indicators.

However, I argue that the usefulness of the environmental IO system is limited to this type of accounting work for the base year that the IO accounts have been constructed for. Part of the consultation process currently taking place among the UK regional authorities and in Scotland is what type of model is required to analyse the impact on sustainability indicator variables that is likely to result from economic disturbances (such as policy changes). An environmental IO system can also be used for *modelling* purposes, and this is being considered as part of the UK and Scottish consultation processes. However, in this dissertation I argue that the assumptions required for this type of application are too restrictive, and instead go on to explain how the environmental IO accounts can be used as a basis for constructing a more flexible CGE modelling framework. I construct an illustrative CGE model of the Jersey economy with endogenous environmental sustainability indicator variables in Chapter 8. In Chapter 9 I use this framework to conduct a number of simulations, which illustrate how an economic-environmental CGE model can be used to track

and explain the movement of chosen sustainability indicators in response to policy changes and other disturbances to the economic system.

Given that Jersey has not yet defined its sustainability objectives I do not attempt to construct or analyse any composite indicators such as ISEW, Green GDP etc. Instead I focus on a number of individual environmental indicators that are relevant in terms of more general environmental objectives that the UK and Jersey are already committed to (such as the reduction of greenhouse gases). I do construct one composite indicator, an Index of Global Warming Potential (the GWP Index). This differs from the type of composite indicators that I have discussed in this chapter in that the weights attached to the components of the GWP Index are determined by technical estimates of the global warming potential of individual air pollutants rather than preferences. Therefore I avoid the problem of determining weights in constructing an index of sustainability, while being able to use it to illustrate how the value of a composite indicator can be determined endogenously within a CGE modelling framework.

However, in future research I do hope to incorporate a wider range of both individual and composite sustainability indicators in the CGE modelling framework. For example, in the case of Jersey, the ongoing public consultation process on local sustainability concerns may provide the opportunity to investigate the problem of constructing a quality of life index, where the weights attached to components are determined by a revealed preference approach, as proposed by Keeney (1974). In the case of Scotland, while the SEAWG has not yet made any recommendations regarding modelling requirements, I am to be involved in an ESRC-funded project on developing a CGE modelling framework that can be used to analyse the impact of sustainability policies in Jersey. This research will involve developing the generic economic-environmental framework constructed in the present study. One of the main elements of the research will be the endogenous estimation of composite indicators such as Green GNP.

Once a full range of sustainability indicator variables is endogenised in the CGE modelling framework, there are a number of potentially useful modelling exercises that can be carried out. For example, in terms of developing and using composite indicators such as Green GDP or the ISEW, the model could be used to carry out sensitivity analysis to assess the implications of including different factors with different weights attached in a set of individual sustainability indicators or a composite indicator. By simulating the system-wide effects of different disturbances or policy actions, the implications of different choices could be assessed. The model would also provide a framework for testing the feasibility of alternative policy options in the presence of binding constraints in the case of the ‘system sustainability’ type of sustainability concern identified here. My argument in Section 2 of this chapter is that this implies development subject to a set of sustainability constraints, which would be represented by indicators where the target level is a binding constraint, and which could be built into the model as such. This would allow different policy options to be assessed on the grounds that their outcomes must be within the feasible solution space imposed by the limited values the constraint variables can take. A (more ambitious) example of this type of exercise would be to explore the possibility of ‘optimal’ policy formulation through maximisation of a social welfare function, as represented by the type of quality of life index proposed above in Section 5, subject to the constraints imposed by endogenous sustainability targets.

However, before any of these suggestions can be implemented in practice, research is necessary to determine how a basic model of the economy must be developed in order to address sustainability concerns. That is to say, the first step is to develop the capacity of the CGE framework to incorporate environmental or other sustainability indicator variables in such a way that their movements can be tracked and explained. This is the purpose of the present study.

In the next two chapters I conduct a literature review to see what general lessons can be learned from existing studies on modelling economy-environment interactions. Then in Chapter 5 I begin the process of developing an empirical model of economy-

environment interaction that can be used to analyse the impact of policy intervention and other disturbances on sustainability indicator variables in a small open regional economy, using the Jersey economy as an illustrative example.

Chapter 3. Modelling Economic-environmental Interactions In A Multi-Sectoral General Equilibrium Framework; The Limiting Case Of Input-Output

1. Introduction

In Chapter 2 I argue that for effective use of sustainability indicators we require knowledge of the transmission mechanism linking policy instruments (or other likely sources of disturbances) to the indicator variables which reflect the chosen sustainability objectives or goals. This will permit explanation of what actually *causes* indicators to move in a given direction, as opposed to the simply descriptive process implied by proposals for monitoring a set of sustainability indicators. I also make the argument that for policy analysis it is necessary to examine the wider effects of any proposed action to alter the value of any single indicator variable. My main concluding argument in Chapter 2 is that an appropriately developed general equilibrium modelling framework, capturing all the relevant behavioural relationships and interdependencies in the economic-environmental system, will provide such a transmission mechanism between disturbances to the system and indicator values, as well as facilitating the necessary system-wide analysis.

My intention in this chapter is to further develop this argument. I do this by introducing multi-sectoral general equilibrium modelling as an appropriate way of simulating and understanding interactions within the economy itself and between the economy and the environment, in order to assess the likely impact of economic and environmental policy actions and other disturbances. In Section 2 I discuss what would seem to be the necessary requirements of a model that is to be capable of capturing the relevant economic-environmental interactions. Then, in Section 3, I examine the fundamental issues involved in designing and building an applied, or computable general equilibrium (CGE) model, introducing the most straightforward and commonly used general equilibrium approach, input-output (IO) modelling, as an example. The starting point of IO is especially appropriate in the present context

because the earliest key developments in economic-environmental modelling were mainly made within the IO framework. I review these early developments in Section 4. Then, in Section 5, I examine how more recent empirical applications of the IO approach to modelling economic-environmental interaction have built on the theoretical and empirical lessons learned from this early research. Finally, in Section 6 I provide a summary and conclusions, including an assessment of the strengths and limitations of the IO approach and discussion of the circumstances in which it may be preferable to adopt a more generalised and flexible CGE framework.

2. Modelling Economy-Environment Interaction

If we are concerned with the impact of the economy on the environment, the first thing we have to consider is what method of modelling the *economy* will allow us to go on to capture the type of interaction with the environment that we are interested in.

One of the most crucial things to note in making this decision is that the nature and magnitude of economic-environmental interaction will vary across different types of economic activity. In particular, patterns of resource use and pollution generation are likely to differ significantly among different industrial sectors in the economy, as well as between different final consumers. Therefore the first requirement of an economic-environmental modelling framework is that it should be possible to have a level of sectoral disaggregation that reflects different resource-use and pollution characteristics. For this reason it is generally agreed that, while there are a number of possible approaches to modelling economic-environmental interactions, one necessary characteristic of such models is that they should be *multi-sectoral* in nature because of the importance of the *composition* of economic activity in governing its environmental impact.

Another key point is that the interdependence *among sectors of the economy itself* will be important in determining the environmental impact of economic activity. To clarify this reasoning, let us consider the example of one of the most commonly

posed questions of economic-environmental interactions. That is, what are the determinants of energy use? Modelling energy use patterns has been a major focus of economic-environmental modelling ever since the OPEC oil crisis in the 1970s. Simple measures of resource extraction (e.g. oil) and waste insertion (e.g. CO₂ pollution) could be made for the economy as a whole, or for any one sector, but this would not help in terms of targeting policy action to reduce environmental damage. This is because from the point of extraction of an energy resource such as oil there is a complex chain of input and output use by and between different sectors of the economy. Output resulting from the resource use at any stage will become either an environmental insertion, in the form of waste emission, or an economic insertion, in the form of input to another sector's activity. Therefore any sector's output level, and therefore its resource requirements and pollution generation, are dependent on demand in other sectors of the economy. So as well as being multi-sectoral, the type of model that is required must also be able to capture interdependencies and feedback effects between *all* the different sectors and categories of final demand in the economy.

In the case of the accounting for energy-use example, a common approach has been to employ input-output techniques to model the entire economic system in order to account for energy use from root, with natural resource extraction, to the point of waste emission into the environment. IO is the simplest form of general equilibrium model, and, as I will argue later in this chapter, may be too restrictive for addressing many questions concerning economic-environmental interaction. However the point I wish to make at this stage is that the popularity of IO in addressing this type of economic-environmental question stems from the approach being both a useful system-wide accounting framework, and part of a wider multi-sectoral *general equilibrium* modelling framework.

In the literature review components of this and the next chapter I hope to demonstrate that the wider general equilibrium approach to modelling economic-environmental problems has become increasingly popular over the last few decades as public and government concerns over energy and pollution issues have grown

world-wide. The main reason cited for this in the literature is that general equilibrium models are built on firm microeconomic foundations and because they incorporate an entire system of behavioural relationships rather than abstracting for some part of the system that is of interest. Moreover, since policy intervention inevitably involves a redistribution of income, another key advantage of the general equilibrium approach is that questions of distribution and equity can be addressed as well as those of efficiency, by identifying the impact of policy changes on different sectors and households. In comparing the general equilibrium approach to modelling the economy with other approaches such as macroeconometric modelling and partial equilibrium modelling, Greenaway *et al* (1993, p.84) state:

The very essence of general equilibrium is that 'everything depends on everything else'. Interdependencies and feedbacks, between policy instruments as well as sectors, have an important impact on outcomes, but in practise are difficult to model in anything other than a general equilibrium framework. Clearly, any approach which is partial equilibrium in flavour faces the 'other things being equal' constraint. The CGE approach not only exposes interdependencies, it offers a facility for modelling them, if necessary in alternative ways.

In terms of the particular problem of energy, Borges and Goulder (1984, p.319) state that:

The nature of the energy problems strongly invites methodologies based on a general equilibrium approach. The interactions between supply and demand, both within the energy markets as well as between the energy sector and the economy as a whole, are far too important to be neglected....The most consistent way to capture these interactions is to model the behaviour of all agents in a general equilibrium framework.

In summary, there is a consensus that general equilibrium modelling has important advantages over an alternative approach like macroeconometric modelling for modelling economy-environment interaction, because of it accommodates sectoral

disaggregation, and over partial equilibrium approaches, because of it models interactions and interdependencies as part of a whole system.

3. Multi-Sectoral General Equilibrium Modelling; The Limiting Case Of Input-Output

3.1 A Basic Introduction To General Equilibrium Modelling

Applied or computable general equilibrium analysis involves simulating numerically the general equilibrium structure of the economy. The use of the term “general equilibrium”, and the framework upon which applied general equilibrium models are built, corresponds to the theoretical Walrasian general equilibrium system, the essential feature of which is that supply equals demand in all markets at a set of relative prices that can be identified. Usually, but not exclusively, the basic underlying theoretical structure in CGE models corresponds to that developed and refined by Arrow, Debreu and Hahn (see Arrow and Hahn, 1971). I should note, however, that general equilibrium models are not restricted to the conventional Walrasian model of universal perfect competition. In terms of essential assumptions all that is needed is that an equilibrium for the economy exists and that it is unique¹. (Greenaway *et al*, 1993, Shoven and Whalley, 1984)

Greenaway *et al* (1993) give a succinct outline of the key issues in laying out the basic structure of a general equilibrium model, which is the first stage in any CGE analysis:

- *Dimensionality* – the level of sectoral disaggregation of total economic activity (i.e. the number of products/production sectors and factors of production)

¹ Spencer (1988, p144) notes that there is typically no theoretical argument guaranteeing uniqueness in most CGE models, and that “currently the presumption of uniqueness is generally made in most cases”. Shoven and Whalley (1984) state that the current working hypothesis is to presume uniqueness until a clear case of non-uniqueness is found.

- *General specification of key relationships* (including functional form) – supply and demand equations (including the interdependencies/interactions between sectors)
- *Collection of benchmark data* – to model the benchmark case/initial equilibrium
- *Calibration of the model's parameters to that data set* – while key parameter values will be pre-specified, calibration involves choosing the remaining parameter values so that the model can reproduce the data set as an equilibrium solution (Shoven and Whalley, 1984)

Once the structure is in place the model is solved for general equilibrium², after which equilibrium relationships and interdependencies can be traced and examined, counterfactual equilibria computed for exogenous changes, and questions of policy evaluation, including distributional effects, can be addressed.

The above summary is intentionally sparse on detail. This is because the CGE framework is a flexible one, within which many different models can be constructed, each with different variations on the basic structure, as will become clear in the rest of this dissertation. Input-output (IO) modelling is the most familiar and widely employed general equilibrium framework. It is, however, a very restrictive and limiting special case encompassed by the more flexible computable general equilibrium modelling framework (Harrigan and McGregor, 1988, McGregor *et al*, 1996). Nevertheless, its simplicity, familiarity and role as a limiting case (alongside the fact that it was the starting point for development of economic-environmental modelling in practice) makes IO a suitable place to begin a fuller discussion of CGE modelling.

3.2 Input-Output As A Limiting Case Of General CGE Modelling

² Any general equilibrium model with price endogeneity and many sectors will generally be impossible to solve algebraically. However the existence of sophisticated algorithms and powerful computing facilities mean that such systems can be solved computationally, data availability being the principle constraint in the presence of appropriate hardware and software. (Greenaway *et al*, 1993)

I have noted above that IO is the most familiar, widely employed, but restrictive, method of general equilibrium modelling. The assumptions of fixed technical coefficients in production and a perfectly elastic supply side mean that IO is normally associated with short-run modelling in an imperfectly competitive, excess capacity setting. (McGregor and Swales, 1994). However IO can, and has, been interpreted as a special, limiting case of a Walrasian (neo-classical) general equilibrium system, with its results representing long-run equilibria, where supply constraints do not bind³.

If we consider IO in terms of the ‘calibration procedures and model use’ identified by Shoven & Whalley (1984)⁴ as typical in CGE modelling:

1. **Data collection.** Data on sectoral demand and supply, factor use and rewards, total GDP etc are collected (using primary and/or secondary sources) to build the **transactions table**, which is essentially an expanded (disaggregated) extension of the national accounts where inter-sectoral flows of goods and services are explicitly included⁵.
2. The transactions table forms the **benchmark equilibrium data set**. Since data are often drawn from a variety of sources, including surveys, the initial table is likely to require adjustments for consistency: in IO tables the value of each sector’s total input must balance with its output. For the table as a whole, total intermediate sales must equal total intermediate purchases, and total final demand must equal total primary input. These are accounting conventions (income = expenditure) which must hold for consistency.

³ For example, Harrigan and McGregor (1988), McGregor and Swales (1994), McGregor *et al* (1996), Shoven and Whalley (1984)

⁴ See Shoven & Whalley (1984) p.1019, Fig.1 – “Flow chart outlining calibration procedures and model use in typical applied general equilibrium model” – reproduced in Greenaway *et al* (1993), p.23, Fig.2.1

⁵ For example, the Scottish Executive produces a 128 x 128 industry by industry IO table (the most recent set of Scottish IO accounts (for the year 1998) are reported in Scottish Executive (2001a).

3. **Choice of functional form and calibration to benchmark equilibrium.** To move from accounting (transactions/*IO tables*) to *IO modelling*, the conventional⁶ basic IO assumption is that:

$$(3.1) \quad X_{ij} = a_{ij}X_j$$

where a_{ij} is a *constant*. What this tells us is that IO assumes fixed technical coefficients in production. For example, suppose X_j is the output of the manufacturing sector, j , and X_{ij} records purchases from the utilities sector, i , to the manufacturing sector, j . This means that we are assuming that utilities purchases (e.g. electricity) are a constant fraction, a_{ij} , of the value of manufacturing output⁷ - i.e. if manufacturing output doubles, so will its required input from the utilities sector. Thus, all IO relationships are of a fixed linear form, and are not subject to any supply constraints. From this a table of intermediate input coefficients is constructed, from which the basic IO model is built.

4. **Analysis using model.** With the model calibrated for the benchmark equilibrium, exogenous demand changes (e.g. policy) can be specified, counterfactual equilibria can be computed, and policy appraisal carried out based on comparison between the counterfactual and benchmark equilibria. Note that IO systems are conventionally *demand driven*, with effects typically stemming from changes in the final demand sector. In IO it is common to consider direct, indirect and induced effects based on the interdependencies between sectors, and to construct multipliers to examine the cumulative impact of these effects. However, an important deficiency of conventional IO is that, given the demand-driven focus, it is silent on prices. Given the assumption of no supply constraints, the IO approach implicitly assumes that there are similarly no price changes in response to changes in final demand. Thus there are no consumption or income effects induced by price changes (though IO *can* incorporate *non-price-induced* consumption and income effects in Type II IO multipliers). Also, because input coefficients are

⁶ There are alternative approaches to IO modelling. For example, Ghosh (1958) has developed a supply-driven IO model. However this has been severely criticised by Oosterhaven (1988, 1989).

⁷ IO theory is stated in physical terms. However, in practice tables are constructed in value terms.

constant, there can be no input substitution effects and, with its assumption of a passive supply-side, evaluation of supply-side policies are necessarily deficient. This is a particularly important point when environmental policies are in question, since these most commonly take the form of supply-side policies. To attempt evaluation, taking account of supply-side factors, these effects would have to be worked out ‘off-line’ (outside the model), on an *ad hoc* basis, then the modeller needs to go back and change the model itself.

To summarise, IO can be regarded as a simple general equilibrium system, with fixed coefficient technologies, an absence of capacity constraints, and an infinitely elastic supply of primary factors. The strengths of the approach are the ease of implementation and potentially high levels of sectoral disaggregation, allowing interactions and interdependencies to be easily traced and identified. The conventional interpretation of IO is that it applies to short-run (impact period) in an imperfectly competitive setting where there are conditions of general excess factor supply (McGregor *et al*, 1996).

However at the start of this section I noted an alternative interpretation of IO: that IO may replicate the long-run equilibrium of a neo-classical model. This is especially the case in a regional context, where perfect inter-regional factor mobility might be approximated in the medium to long run. McGregor *et al* (1996) demonstrate that in a wide range of regional economic models, IO accurately describes the long-run response of activity to a permanent change in aggregate final demand. They explain that many regional models do not operate as IO systems in the short-run, but may do so in the long run. This is particularly likely where there is only one non-produced input, labour, whose long-run supply is rendered perfectly elastic, through migration, and where the region is perfectly integrated into the national financial markets. Note also that by this reasoning the classical general equilibrium model, with a fixed set of factors, may be the opposite limiting case – i.e. the first period (short-run).

4. Early Developments In Economic-Environmental IO Modelling

4.1 IO And The Materials Balance Principle

In the late 1960's and early 1970's there was significant research interest in modelling the economic-environmental system using the IO approach. The central focus of the earliest studies was to capture and understand the implications of the 'materials balance principle' (MBP). The MBP arises from the 1st Law of Thermodynamics, which states that matter can neither be created nor destroyed by human activity; rather it can merely be transformed from one state to another. In terms of the current discussion, what this means is that any waste products/residuals discharged into the environment as a result of economic activity are the necessary corollary of the extraction of material resources from it. This is because the system in which all economic activity takes place, earth's natural environment, is a thermodynamically closed system in that it exchanges energy but not matter with *its* environment (incoming solar radiation is balanced against outgoing energy). Therefore the mass of materials extracted from the environment in any period must necessarily be returned to it. This leads to the interpretation of the MBP as implying an equilibrium relationship between the economic and environmental systems, which can be summed up in the following statement:

*The mass of residual flows into the environment from all forms of activity in
the system equals the mass of resource flows from the environment*

Perman *et al* (1996, p.11)

Note, however, that this necessary return of residuals need not be instantaneous. There may be significant delays in the timing of the flows to and from the environment. The return period may be effectively instantaneous – e.g. cutting down a tree to build a fire. Or, at the other extreme, natural resources such as iron ore may be extracted and transformed into steel to add to the capital stock in the form of building infrastructure which will last for perhaps hundreds of years. Even after the collapse or destruction of the building, the disintegration of the structural steel may take many more years. So we can say that the MBP is a relationship which will hold where the world is in static, very long run equilibrium, so that no net stock accumulation takes place. That is to say, the stocks of buildings, plant, other capital

and consumer durables do not change in magnitude. (Common, 1995, 1998, Perman *et al*, 1996, 1999.)

The importance of the MBP, in the present context, would seem to be less one of whether the implied equilibrium relationship holds (which could not be expected in any timeframe relevant to economic analysis⁸), but that it may be regarded as providing a coherent framework for understanding economic-environmental interdependence. That is to say, if we wish to undertake a full and comprehensive analysis, recognition of the MBP could be argued to point to an examination of the entire economic-environmental system of interaction and interdependence, with recognition of the causal link between natural resource use, economic activity and pollution.

Proponents of introducing the MBP to economic analysis, such as Common (1995, 1998), tend to argue that economists have generally ignored this law in studies of natural resource use and pollution in economic systems. Whether or not this is a valid general observation (abstracting for now from the question of whether the MBP is actually a useful or relevant concept to economic-environmental analysis) the criticism cannot be levelled at the earliest attempts at economic-environmental general equilibrium modelling. In fact attempting to capture and analyse the implications of the MBP would seem to have been the central focus of this work, a point that is confirmed by Victor's (1972) framing his review of six key early models⁹ in terms of attention to the MBP.

What these early models seem to have been attempting is to construct what Miller & Blair (1985, p.252) refer to as a "fully integrated model" or "economic-ecologic models" (p.236). In other words they attempt to capture flows within and between the sectors of the economic and environmental systems in an IO framework along the lines of an inter-regional model (i.e. with 'the economy' as one region and 'the

⁸ The timeframe required for the equilibrium identity implied by the MBP would be thousands of years, given the length of time that many capital goods, such as buildings, are known to survive. It is not clear that such an equilibrium concept is of value even as a conceptual tool.

⁹ Victor (1972) reviews and compares the models of Cumberland (1966), Daly (1968), Ayres & Kneese (1969), Isard (1969), Leontief (1970), before detailing his own environmental IO model.

environment’ as the other). The idea is that this type of framework will capture the flow of materials around a thermodynamically closed system implied by the MBP, with no matter destroyed, and only transformed from one state to another. For example, resources flowing from one of the environmental ‘sectors’ being transformed into goods and services by one or more of the economic sectors, with any residual material flowing back into one or more of the environmental ‘sectors’.

There are two fundamental problems that render IO unsuitable for this type of application, and these are discussed in the next section. However, the key point arising from Victor’s (1972) study of this early research is that it has proved impractical, if not impossible, to properly capture the full system of economic-environmental interactions implied by the MBP. This conclusion arises from the lack of success of two of the first economic-environmental IO modelling projects that attempted to capture the full system of interactions using multiple economic and environmental sectors and commodities: Daly (1968) and Isard (1969).

Figure 3.1 – Daly’s (1968) Economy-Environmental IO System

	Economic Sectors (2 industries and households)	Environmental Sectors (7 “transformation” sectors)	Total output
Economic Sectors (3)	$q_{1,1}$	$q_{1,10}$	Q_1
Environmental Sectors (7)	... $q_{10,1}$	... $q_{10,10}$	... Q_{10}

Daly’s (1968) attempt did not really get beyond trying to construct the necessary set of IO tables, his model being regarded as unworkable principally because of methodological problems (independent of questions of data availability and reliability). Without going into too much detail, the two basic problems associated with Daly’s (1968) model relate to the issues of internal consistency and how technical coefficients are calculated. Both problems are related and stem from the

fact that Daly (1968) attempts to balance the entire system by summing across rows that include both economic and environmental commodities – see Figure 3.1 above.

The output of each economic and environmental sector is given along a row of Daly's (1968) IO table¹⁰ and includes both the economic and environmental (i.e. waste/pollution) commodities produced by that industry. For example the output of the first economic sector, Q_1 is given by

$$(3.2) \quad Q_1 = \sum_{j=1}^{10} q_{1j}$$

However the model has non-comparable units in that the outputs of economic commodities are valued at market prices, but the environmental commodities, for which it is assumed no markets exist, have no market prices and can only be measured in physical units (with zero prices). Daly (1968), however, seems to see no problem in summing across non-comparable units in this way, and the second problem arises from the fact that he goes on to use these output 'totals' to calculate the production coefficients for each of the economic and environmental sectors. For example, the two economic (production) sectors in Daly's (1968) model are agriculture (1) and industry (2); the technical coefficient showing industrial purchases (in dollars) required to produce one (\$) unit of agricultural output is given by

$$(3.3) \quad a_{21} = q_{21}/Q_1$$

However, from Daly's (1968) table (Figure 3.1 above), and from equation [3.2] we know that Q_1 is the sum of both economic goods (measured in dollar terms) and environmental 'goods' (measured in physical terms). As argued by Victor (1972), this would seem to render Daly's (1968) technical coefficients as meaningless as his output totals. For these reasons alone, Daly's (1968) model, which was never applied empirically anyway, is regarded as useful only for descriptive but not analytical purposes.

The next attempt to capture the full system of economic-environmental interactions, also using multiple economic and environmental sectors and commodities, was by Isard (1969).

Figure 3.2 – Isard’s (1969, 1971) Economy-Environment IO System

	Economic sectors (activities)	Environmental sectors (processes)
Economic Commodities	A. <i>Economy-economy</i> Std intersectoral coefficients	B. <i>Economic-environmental</i> Economic output-pollution coefficients
Environmental Commodities	C. <i>Environment-economy</i> Economic natural input coefficients	D. <i>Environment-environment</i> ‘Inter process coefficients’

What the intended dimensions of Isard’s (1969) four matrices are is not clear – even Victor (1972), as a proponent of Isard’s (1969) work, does not seem to be sure of the mechanics of the system¹¹. Nonetheless, Isard (1969) does seem to be widely regarded as having overcome the methodological problems associated with Daly’s (1968) model. Forssell & Polenske (1998) explain that the problem of non-comparable units is tackled by adopting a commodity-by-industry rather than an industry-by-industry approach in constructing his IO tables, to allow each industry (economic sector) to produce both its own (economic) product and an associated waste product as separate but related outputs. The key point is that Isard (1969) distinguishes between the economic and environmental outputs (inputs) from (to) the economic and environmental sectors, allowing him to balance and calculate the technical coefficients for each sub-matrix separately (without summing across incomparable units).

However, Victor (1972) explains a crucial problem with Isard’s (1969) model: that of actually building the necessary database. Isard and his colleagues did try to apply his model to the Plymouth Bay area in Philadelphia in the USA (see Isard & Langford,

¹⁰ A fuller representation of Daly’s (1968) IO table is given as Table 2 on p.402 of his paper.

1971), but encountered significant data problems, particularly with respect to his equivalent of matrix D, the environmental system. This is what Victor (1972) identifies as the fundamental problem with the Isard project: the fact that while a significant body of data exists for the economic system, there are very few established data for the environmental system which can be drawn on to put Isard's (1969) model to work. Other authors, such as Miller & Blair (1985), have also argued (in considering the feasibility of actually building what they refer to as a "fully integrated economic-ecologic model" (p.253)) that the availability of data for the environmental (ecosystem) sub-matrix is the biggest problem.

4.2 Two Fundamental Problems With Modelling The Full Economy-Environment System In The Manner Proposed By Isard (1969) And Victor (1972): Geographical Focus And The Stocks-Flows Problem

Basically, then, the general opinion in the literature appears to be that the major problem is the fact that economics, and science in general, lacks the knowledge about how the environmental system operates to properly model the microstructure of the environment. I would also argue that a more fundamental problem exists in that the lack of information about the structure of the environmental system means that it is not possible to even construct a set of IO *accounts* for the full economic-environmental system. The availability of a set of IO accounts is a necessary precursor to the construction of any IO *model*. I return to the issue of making the (important) distinction between accounting and modelling shortly. Before I do this, though, I wish to debate what appears to be a common conclusion in the literature that *data* problems are the main barrier to the successful construction of a 'full integrated' IO model of the economic-environmental system. It would seem to me that the problem is a much more fundamental one than this.

In light of the problems encountered by Isard (1969) and Isard & Langford (1971) in constructing and putting into practice the fully integrated economic-environmental IO modelling system summarised in Figure 3.2, Victor (1972) discusses the progress

¹¹ See discussion in Chapter 2, Section E, of Victor (1972).

that *can* be made in building a modelling system based on IO principles. This discussion concentrates on the issue of data availability. He argues that research effort should focus on constructing Isard's (1969) matrices B and C, because these serve to link the economic and environmental systems, both relating directly to industrial processes "about which a considerable amount of data either already exists or can be collected with relative ease" (p.47). Victor's (1972) argument is that this *would* allow modelling of the causal link between the economy's use of natural resources and its generation of pollution, which has been identified as the key implication of the MBP, even though the relationship in the opposite direction would not be captured. This is the type of model, referred to by Miller & Blair (1985) as a "limited model" (p.253) (relative to the 'fully-integrated' Isard-type model), which Victor (1972) developed, and which is frequently cited in the literature as the alternative economic-environmental IO approach to the more commonly adopted Leontief-type approach. (I discuss the Victor and Leontief approaches below, in Section 4.3.)

However, Victor's (1972) conclusion that attention should focus on developing Isard's (1969) matrices B and C is qualified by the desirability of knowing how the material (waste) inputs to the environmental system (matrix B) subsequently affect the material outputs (resources) of the environmental system back to the economy (matrix C). In other words, Victor (1972) seems to regard modelling the full economic-environmental system (in order to capture the transformation of waste into environmental resources in Isard's (1969) matrix D) as a step that should be taken when and if the availability of environmental data allows it.

While not disputing the importance of the processes that occur within environmental system, my argument is that modelling the full system of economic-environmental interaction is likely to be an inappropriate and even misleading development in economic-environmental IO modelling. Two issues underlie this conclusion: geographical focus and the stocks-flows problem.

4.2.1 Geographical Focus

The first issue I would like to discuss is the fact that the modelling system proposed by Isard (1969) and illustrated in Figure 3.2 is a conceptual (theoretical) one where the interactions implied by the MBP are captured within a *closed* system consisting of ‘the economy’ and ‘the environment’. However it is only at the *global* level that the economic-environmental system will be closed in this way; at any sub-global level there will be economic and environmental interaction with the wider system. The crucial point is most empirical IO models (or any other general equilibrium model) are in fact likely to focus on geographical areas or regions that are *sub-global*, meaning that the system illustrated in Figure 3.2 cannot be modelled as a closed system incorporating all economic and environmental impacts.

There are really two factors to be aware of here: the first is the fact that most models are built for *economies*, which tend to be defined in terms of political boundaries. Any interactions with the wider economic system can be dealt with by modelling trade flows etc, about which well-documented data will almost certainly be easily available for most economies. However the environment cannot be defined by economic or political boundaries in the same way as the economy can; for example, while it is relatively straightforward to model the Scottish economy, how would we even define the Scottish ‘environment’? Common (1995) defines four ways in which the environment facilitates economic activity (and human life in general): provision of natural resources, absorption of waste, provision of amenity services, and provision of life support systems. Unless Scotland, which is defined by political boundaries, could be considered as a self-contained eco-system, capable of performing all four of these roles in such a way as to independently support the Scottish population and economy, reliance on the wider global environment must be taken into account. So the first factor is that in practice economic-environmental models are, almost without exception, built for geographical areas or regions that are based on economic or political boundaries, and it is highly unlikely that these would coincide with environmental boundaries.

However, even if there is delineation according to *environmental* boundaries rather than political/economic ones¹², it is still highly unlikely that this would represent an environmentally *closed* system. Referring back to the definition of the MBP given in Section 4.1, note that it is only the global environment that is a thermodynamically closed system, so any sub-global region would, by definition, have to be environmentally open. While, as I have noted above, accounting for system openness is relatively straightforward in the case of an economic system, the same cannot be said for an environmental system. In the case of *marketed* environmental commodities this may not be such a great problem, since resource extraction and the consequent generation of pollution can be attributed to the region/area of origin using data on trade flows. However most environmental flows (i.e. Daly's (1968) 'free' goods such as the 'products' of the atmosphere, hydrosphere etc, or the energy provided by the sun) are not marketed and therefore cannot be accounted for in this way. Victor (1972) draws attention to the problems encountered by Isard and his colleagues in gathering data for and modelling one relatively small region; however it is difficult to see how such data could be gathered for a sub-global region in any case. Even if it were, the problems encountered by these researchers would be magnified if the entire global environmental system had to be modelled in order to capture the full environmental impact of the single area/region being modelled, and the consequent feedback effects from the global environment.

So, in summary, I would argue that the first problem is that while in theory it is desirable to model the full system of economic-environmental interactions implied by the MBP, in practice this would only be a meaningful exercise if the system being modelled were the global one. If this were attempted, it seems to me that the global *economy* would have to be modelled as a *multi-region* system (in order to capture trade flows) with each regional economy interacting with a *unified global environmental system*. Since most empirical models focus on sub-global areas defined in terms of political and/or economic boundaries, I would argue that the best that can be done is to model those *quantifiable* extractions from and insertions to the

¹² For example, Kamat *et al*'s (1999) CGE model of the US Susquehanna River Basin, which is delineated on the basis of environmental homogeneity in terms of climate and the impact of climate change.

environment that take place as part of local economic activity. In other words, this would involve incorporating those extractions and insertions of materials to and from the environment that can be readily accounted for (use of natural materials and pollution generation by local economic agents) in what Miller & Blair term a “limited” environmental IO framework. (However, note that if it is considered desirable that a model should take account of any resource use and/or pollution generation embodied in imports and exports to/from the local economy, we come back to the requirement of a global or at least a multi-region model.)

As argued by Victor (1972), a limited IO approach to modelling economy-environment interaction such as this *does* involve taking account of the MBP, but is not constrained by it. However, this is only in so much as it involves taking account of the fact that there *is* a flow of natural materials through the economy, and tracking the causal relationship between natural resource use and pollution. Victor (1972) goes on to argue that attention to the MBP can (at least in principle) be formalised by introducing balancing accounting identities that must hold in the model (these are formally stated in Victor (1972, pp.61-63)). He explains that satisfying such identities would require that the mass of natural material inflows to economic activity must equal the mass of outputs discharged back to the environment as waste products/pollution *plus* any material accumulations within the economy (i.e. accumulation of capital and consumer durables). (However, as I explain in more detail in Section 4.3, it would seem that while Victor’s (1972) materials balance accounting identities may be *analytically* correct, actually satisfying them in practice would be virtually possible as this would seem to require that *all* materials flows be tracked at the atomic level.)

4.2.2 The Stocks-Flows Problem

There is a second problem that leads me to the conclusion that even if the system being modelled was the *global* system, the type of circular flow framework illustrated in Figure 3.2, and proposed as an ideal by authors like Isard (1969) and Victor (1972), is an inappropriate one. While the view of the authors cited above has

been that the main problem with constructing matrix D (the environment-environment system) has been one of data availability, I would argue that construction of such a matrix is inconsistent with the notion of a fixed coefficient IO system.

My argument is that core problem lies in the fact that that the system of IO relationships illustrated in Figure 3.2 (just like any IO system) is a system of *flow* relationships. However the environment-environment system (matrix D) is likely to be dominated by *stocks*. Indeed it is the importance of limited stocks in the environmental system that drives the whole sustainability debate. However the presence of and importance attached to finite stocks in the environmental system introduces significant problems if we attempt to model the economic-environmental system as an IO system.

First and foremost there is the problem that IO abstracts from the idea of fixed capacity: in Section 3.2 I explained how IO assumes an infinitely elastic supply of all factors (i.e. to double all outputs we can simply double all inputs). The question of sustainability, however, arises from the fact that the economic-environmental system is constrained by fixed, or at least limited environmental capacity (i.e. it may not be possible to double all inputs). This is difficult to reconcile with the notion of matrix D as a system of fixed coefficients. In Section 2.1 of this chapter, and Section 7.2 of Chapter 2, I have discussed how stock levels in the environmental system affect flows of resources from the environment to the economy, and are affected by flows of waste and pollutants from the economy back to the environment. This suggests to me that the value of the coefficients in matrix D will *not* be fixed; rather they will be dependent on the magnitude of the flows from the economy to the environment, and that this will in turn constrain flows back to the economy from the environment. In other words, the coefficients in matrix D will be *endogenously* determined, and will therefore not be fixed. Moreover, it is the case that there are significant time lags involved in changes to environmental stocks as a result of flows of pollution from the economy to the environment, and these are simply not consistent with the time frames associated with IO modelling.

My argument, then, is that what all this would seem to imply is that the idea of augmenting the basic IO system with a series of fixed coefficient matrices to form some type of circular flow is inconsistent with the concept of an unconstrained IO system. The only way we could have fixed coefficients in all four matrices is if the supply of both economic and environmental factors were completely unconstrained and non-stock dependent. However, there is another problem with this notion of a circular flow system: the question of what would drive such a system. The problem is that IO is essentially a 'one-way street', where the magnitude of flows through the fixed coefficient system is driven by the vector(s) of final demand in the economy. These demands are determined exogenously, meaning that the IO system is open-ended. However the idea of a circular system such as that illustrated in Figure 3.2 seems to be to be one of a closed system, where everything is determined endogenously; this is inconsistent with the conventional workings of an IO system.

It would seem that the problem for those interested in using IO to model the MBP arises in the distinction between IO as an *accounting* framework and IO *modelling*. It is clear to see the appeal of the former to those interested in the MBP: the essential feature of a set of IO accounts is that all inputs must balance against outputs. Since the central premise of the MBP is that environmental extractions must equal environmental insertions, it therefore seems natural to carry the accounting conventions of IO across to *environmental* inputs and outputs.

Making the distinction between accounting and modelling is crucial. For one thing, note that the problems encountered by Isard (1969) in attempting to construct a fully integrated economic-environmental system are not confined to modelling: he was also unable to construct a complete set of IO *accounts* for the system. In the next section, where I review Victor's (1972) model, I will discuss the problem of how a materials balance accounting system would appear to require measurement at the atomic level, rendering even the notion of IO accounting of the full economic-environmental system as completely impractical.

However, abstracting from this problem for now, a critical point is that even if construction of a full set of IO accounts for the economic-environmental system was possible, this does not mean we have an IO *model*. In Section 3.2 I explain that development of an IO model requires the assumptions of universal fixed coefficients and perfectly elastic supply of all factors. However it is at this point that the problems discussed above arise for those trying to model the *entire* economic-environmental system and the MBP in an IO framework. This is because such a system is dominated by constraints on environmental stocks, which affect and are affected by the flows to and from the economy. Moreover, in attempting to close the IO system with some notion of a circular flow of materials around a (thermodynamically) closed economic-environmental system the causal ordering between input use and generation of outputs (be they economic or environmental) is lost. This is because there is no clear identification of inputs to and outputs from the IO system, or what drives any causal relationships in the system. In a conventional IO system the causal relationship between the production of outputs and the use of inputs is driven by exogenously determined final demands; however in the closed system proposed by authors like Isard (1969) and Victor (1972) nothing appears to be exogenously determined. In other words, in trying to adapt IO to capture the full implications of the MBP the appeal of IO for this purpose is lost. By making environmental inputs (natural resources) to the economy endogenous to the IO system we lose the idea of (exogenous) environmental extractions (resource use) by the economy balancing against the resulting economic outputs and insertions back into the environment.

Therefore my argument is that Victor's (1972) recommendation that modellers focus on developing matrices B and C *should not* be qualified by the desirability of closing the system with construction of the fourth environment-environment matrix (Isard's (1969) matrix D). Rather, we should focus on the value that can be gained from modelling extractions from and insertions to the environment resulting from economic activity. In terms of the sustainability policy proposals for using target values for sustainability indicators that I discuss in Chapter 2, this may involve imposing constraints on resource use and pollution generation that have been

exogenously determined in light of some separate research. Or, if environmental feedback effects are likely to be important in the case of the target economy, these could be estimated using more some more appropriate type of model and fed back into the IO system.

4.3 The Key Early Developments In Economy-Environment Modelling: Victor (1972) And Leontief (1970)

4.3.1 The Victor (1972) Model

Victor’s (1972) own model¹³ incorporates environmental (or ‘ecologic’) commodities as extractions from and insertions to the environment by the economy, with no attempt to model any feedback effects from the environment as a result of the latter. Basically he follows Isard’s (1969, 1971) methodology in building what are referred to above as matrices A, B and C, but misses out the problematic matrix D, thus constructing what Miller & Blair (1985) term a ‘limited model’ of economic-environmental interaction. Matrix A, as I have explained above, is the standard IO matrix of the economic system. Victor (1972) then augments this basic IO model of the economic system to incorporate (matrix B) natural resource inputs to production for m industrial sectors (and direct consumption by f final demand categories). For each industrial sector, natural resource (‘ecologic commodity’) use is given by

$$(3.4) \quad R_{ij} = \beta_{ij}X_j \quad \forall j = 1, \dots, n, i = n + 1, \dots, z$$

R_{ij} is defined as the input of the i th ecologic commodity used by the j th industry (there are n economic commodities and $z-n$ ecological commodities), and β_{ij} is defined as the quantity of the i th ecologic commodity used by the j th industry per unit of marketed output of the j th industry (X_j). Victor (1972, pp.76-77) explains that the ecologic commodity inputs are defined by and extracted directly from land, air or

¹³ Victor’s model is explained in Chapter 3 of Victor (1972), with the layout of his economic-environmental IO table and IO matrices given in Table 4, p.56.

water sources, but says that, apart from this identification of source, these are introduced to the model in the same way as primary inputs¹⁴.

The subsequent generation of pollution/waste products by each of the industries is treated in a similar way (matrix C), the ‘ecologic commodity outputs’ of an industry being proportional to that industry’s marketed output:

$$(3.5) \quad F_{ij} = \gamma_{ij}X_j \quad \forall j = 1, \dots, n, i = n + 1, \dots, z$$

F_{ij} is defined as the output of the i th ecologic commodity produced by the j th industry, and γ_{ij} is defined as the quantity of the i th ecologic commodity produced per unit of marketed output of the j th industry (X_j). In a similar way to the resource inputs, the land, air or water sink to which they go defines the ecologic commodity outputs.

Victor (1972) argues that the key feature of his approach is attention to the MBP by modelling the flow of materials through the economy from the extraction of resources from the environment to be used in economic activities, to the subsequent return of pollution/waste back to the environmental. He also introduces accounting identities that he says must be met to ensure that the flow of materials to and from the environment, net of any material accumulations within the economy, is consistent with the MBP. This of course raises the question of how *all* materials flows could actually be tracked in order to allow this condition to be met. Indeed in Victor’s (1972) empirical application of his model¹⁵, he freely admits that the materials flows modelled are limited to “four types of water input and twenty-seven types of water, air and land outputs” (p.99). He does not, however, address the problem of how the materials balance identities can be satisfied under this limited inclusion of environmental inputs and outputs. It would seem that this would only be possible if

¹⁴ Though, as will be discussed below, one crucial difference between standard (economic) primary inputs, such as labour and capital, and natural resource inputs is that markets may not exist for many of the latter. (One implication of this is that natural resource inputs used in the production of output do not enter into the *value* of output, as recorded in most conventional IO systems.)

¹⁵ See Victor (1972) Chapter 4, where he attempts a practical application of his analytical model for water-use and waste disposal in Canada in 1961.

the materials extracted from the environment in the form of the four water inputs are transformed exclusively into materials contained in economic commodities and/or the 27 water, air and land waste outputs identified in the model.

It seems to me, however, that there is a much more fundamental problem here. I have already explained above how the main problem with Daly's (1968) model related to incompatible units of measurement: economic commodities tend to be reported in units of monetary value (£) while non-marketed environmental 'commodities' tend to be measured in physical units (weight or volume). This is not a problem for a 'limited' model, which incorporates only environmental inputs and outputs to and from the system, if the technical coefficients are determined in the manner defined above for the Isard (1969) model. (In other words the environmental input coefficients (the β_{ij} in equation (3.4)) should show the physical amount of environmental input i used to produce one monetary unit of the economic good j . The environmental output (waste) coefficients (γ_{ij} in (3.5)) should show the physical output of the environmental 'bad' i per monetary unit of the economic good j .) However, Victor (1972) notes that for his MBP balancing identities "to be a correct representation of this law of conservation [of mass], inputs and outputs must be measured in mass" (p.61). In other words, if we want to track the flow of materials *through* the system, all economic commodities must be measured in (or converted to) physical units, which, according to Victor (1972) should be weight as a generally accepted measure of mass.

In practical terms, converting IO accounts into physical units is problematic: IO data are almost invariably collected in monetary units because value is the common denominator for the heterogeneous economic outputs of most industrial sectors. However, this problem can be overcome. Nonetheless, there would seem to be a more fundamental problem in terms of exactly *what* we would have to measure and model in order to determine whether Victor's (1972) balancing identities are satisfied – i.e. what are the 'materials' we must track? I would argue that the real problem here lies in the fact that the 1st Law of Thermodynamics operates at the level of atoms: the transformation of materials that takes place during economic production

and consumption activities will involve a complex reorganisation of matter at the *atomic level*. Therefore, in order to track the flow of materials in the manner Victor (1972) suggests, surely we must track the molecular breakdown of natural resources and the reorganisation of the basic physical elements (e.g. carbon, oxygen etc.) from natural inputs into a combination of economic goods and waste. This would be a hugely impractical task.

As we will see below, a number of later economic-environmental IO studies may be identified as following Victor's (1972) approach in so much as the causal relationship between resource use (mostly energy use) and the generation of pollution is explicitly accounted for by tracking things like energy-use through the economy. None of the models reviewed in this chapter, however, attempt to balance the type of accounting identities suggested by Victor (1972) to check that the flows of materials actually balance in the manner implied by the MBP. This may reflect the type of concerns raised here with respect to the feasibility of tracking the flow of *all* materials through the system, or it may be the case that modellers do not generally regard this as a useful exercise.

However, the crucial point suggesting that most economic-environmental IO models are not in fact strictly 'Victor-type' models (even if they explicitly incorporate equations similar to (3.4) and (3.5) above) is the fact that Victor's (1972) intention is to model a full range of natural resource extractions directly from environmental *sectors*. I would argue that the key point is that Victor (1972) does not primarily define natural resources and pollution by 'type' of resource (e.g. oil, coal, gas etc) or pollutant (e.g. CO₂, NO_x etc). Instead he first defines all resource and pollution/waste flows according to the three environmental sectors identified as 'land', 'water' and 'air' that they come from/go to (i.e. environmental source and destination).

Forssell & Polenske (1998), raise the point that in practice it is difficult to model these types of 'sector' because the appropriate data cannot generally be obtained for them. One problem is that it would seem difficult to apportion environmental resources/pollution flows to specific individual sectors. However the data availability

problem is most likely to stem from the fact that the inputs from *environmental sectors* are likely to be *non-marketed*. The data required for economic modelling are generally established from recording market activities (or asking human beings directly). In most IO models that incorporate natural resource use, the source of these materials tends to be *economic* sectors whose activity is identified as their extraction/refinement/supply, and data (in physical and/or monetary units) on the use of materials is obtained from recording market activities. However, there can be no market activity between economic sectors and *environmental* sectors, since the latter are *non-human sectors*, and as such cannot participate in market activity, meaning they cannot be treated as a source of supply in the economic sense.

The point is that we cannot treat the relationship between the economy and the environment as an economic one unless we can attach a value to economic commodities so that when we use environmental resources we *pay* for doing so. If an economic good is scarce, and therefore valuable, it will command a price. However, while we may know that an environmental commodity is both scarce and valuable, if it does not command a price we do not have to pay for its use, and therefore an economic relationship does not exist. That is unless *property rights* can be assigned to the environmental commodity. However if the transactions costs involved in the assignation of property rights are considered too high relative to the value of the environmental commodity it will be the case that a scarce environmental commodity will not command a price. The implication of this is that no market transaction will be required to secure the use of that commodity.

However, even where property rights *are* assigned to environmental commodities the use of natural resources will be recorded as a relationship between *economic* sectors, rather than between economic sectors and Victor's (1972) environmental 'sectors'. Profits from the extraction and supply of natural resources such as fossil fuels will accrue as economic rents gained by firms in oil/gas extraction sectors that hold property rights to known stocks of these resources. When an energy company extracts oil or natural gas from the environment, there are no costs to be paid *to the environment* as such. Rather the costs involved in this activity are extraction costs

that will be paid to other *economic* sectors (e.g. equipment hire, labour etc), with the firm holding property rights retaining the rents that represent the cost to the environment.

The problem still applies but is less pertinent with Victor's (1972) framework for modelling pollution. Again there is the problem that we do not have to *pay* the environment for its services as a waste sink. Any compensating payment for polluting the environment would arise as a result of a feedback effect from the economy to the environment if the utility of other economic agents (consumers or producers) were affected by environmental damage. However Victor (1972) is not trying to model the consequences of such feedback effects on the economy (whereas, in the case of natural resource extraction he *is* trying to model the feedback effects on the environment resulting from economic activity). The main problem that may be encountered with Victor's (1972) treatment of pollution in equation (3.5) in terms of identifying precisely which sector polluting outputs flow to.

It is clear where Victor's (1972) notion of environmental 'sectors' emanates from. The environment produces a lot of resources, which is what would motivate defining and treating environmental sectors like economic production sectors (i.e. an environmental sector is where some process takes place that transforms one type of environmental materials into another). It is also clear that, with his 'limited' version of Isard's (1969) 'fully integrated' economic-environmental system, Victor (1972) is attempting to capture the idea that the environmental system produces natural resources whose formation is affected by the insertion of waste products into the environmental sectors by the economy. Victor (1972) would see the main problem with his model as being its incompleteness (his argument that matrix D should be constructed if and when appropriate data becomes available). Conversely, I would argue that the main problem with Victor's (1972) model is that the importance attached to the impact of insertions of waste on future resource production by the environmental 'sectors' implies that the environmental system is *supply-driven*. This has the implication that a conventional IO approach is an inappropriate framework for modelling.

However, conceptual problems aside, I would identify the key problem that is likely to be met in the practical application of Victor's (1972) approach as being the treatment of non-marketed natural resources as inputs to economic activity. *Marketed* natural resource inputs, on the other hand, can and have been adequately dealt with, along with pollution generation, in what has been the most influential, and most commonly cited, development in economic-environmental IO modelling: the work in the 1970's by Leontief, the inventor of IO analysis, and his colleagues.

4.3.2 The Leontief (1970) Model

The Leontief approach to economic-environmental IO was first introduced in analytical form in Leontief (1970) and an early empirical application (to the US economy) can be found in Leontief & Ford (1972). Leontief was not really concerned with modelling the materials balance principle, focussing instead on the question of pollution as a negative externality, or an undesirable by-product of production and consumption activities in the economy, and the associated costs of pollution elimination. Victor (1972) comments that Leontief's (1970) approach reflects what seems to be a greater concern with using economic-environmental modelling as a guide to policy rather than for description of the implications of the MBP. A key factor here is the point raised above regarding the focus on (a sub-set of) particular *types* of pollution that are thought to be particularly harmful by-products of production and consumption activities, rather than attempting to account for the balance of *all* materials flows to and from environmental sectors.

Basically, Leontief's (1970) development in economic-environmental IO modelling was to introduce what Miller & Blair (1985, p.237) class as "generalised input-output analysis". Instead of introducing environmental sectors that interact with the standard economic sectors, the Leontief approach involves augmenting the standard (economic) technical coefficients matrix with additional rows and columns to reflect pollution generation and abatement activities by economic sectors. Leontief (1970) simply shows one (unidentified) pollutant as a single additional row in the matrix of

coefficients, with the assumption that pollution is produced by each sector as a fixed proportion of output. In the empirical application of Leontief & Ford (1972) this is generalised to the case of five specific (air) pollutants, with an additional row in the matrix for each, representing the pollution coefficients for each industry and each pollutant. There are also additional columns representing different processes for partial or complete elimination of these pollutants as pollution abatement sectors, with the individual cells in each pollution abatement column showing the input requirement from the other economic sectors to carry out pollution abatement activities. The cells in each pollution abatement column that correspond with the pollutant outputs (rather than the outputs of the economic sectors) show the amount of each respective pollutant generated by the pollution abatement sector. The part of the final demand vector that corresponds to the pollution generation rows represents the level of pollution society is willing to tolerate, meaning that the gross outputs of the pollution ‘sectors’ will show the amount of pollution eliminated by the abatement sectors.

Figure 3.3 – The Leontief IO System

Sub-matrix A_{11} ($m \times m$) Inter-industry coefficients	Sub-matrix A_{12} ($m \times (n-m)$) Input structure coefficients of specific anti-pollution activities
Sub-matrix A_{21} ($(n-m) \times m$) Direct pollution output coefficients	Sub-matrix A_{22} ($(n-m) \times (n-m)$) Pollution output coefficients for the anti-pollution activities

Leontief & Ford (1972) summarise the approach in the partitioned matrix reproduced in Figure 3.3¹⁶. The four different types of coefficients contained in the four sub-matrices are defined as follows:

A_{11} : a_{ij} – input of good i per unit of output of good j , produced by sector j

¹⁶ See Leontief & Ford (1972) p.10.

(where $i, j = 1, \dots, m$)

A_{12} : a_{ig} – input of good i per unit of eliminated pollutant g , eliminated by sector g
(where $i = 1, \dots, m$, and $g = m + 1, \dots, n$)

A_{21} : a_{gi} – output of pollutant g per unit of output of good i , produced by sector i
(where $i = 1, \dots, m$, and $g = m + 1, \dots, n$)

A_{22} : a_{gk} – output of pollutant g per unit of eliminated pollutant k , eliminated by sector k (where $g, k = m + 1, \dots, n$)

However, Leontief (1970) notes that in practice it may be difficult to identify the ‘anti-pollution’ (pollution abatement) industries necessary to partition the IO matrix in this way. Where this is the case he explains that there is no internal consistency problems if the subdivision is limited to identification of matrices A_{11} and A_{21} , since this simply means a more aggregated approach where any anti-pollution activities are included among each sector’s normal economic activities. In practical applications it has in fact proven difficult to separately identify pollution abatement sectors and ‘Leontief-type’ economic-environmental models have generally been limited to modelling pollution generation through matrices A_{11} and A_{21} . This is because data are generally not available to separately identify the pollution abatement activities of firms in the manner that would be required to construct matrices A_{12} and A_{22} above. Leontief himself found pollution abatement difficult to model in practice, with Leontief & Ford (1972) only managing partial construction of sub-matrices A_{12} and A_{22} .

In Section 5 I explain how most empirical applications of economic-environmental IO modelling have taken this ‘Leontief-type’ approach, mainly to modelling pollution generation, rather than adopting a ‘Victor-type’ MBP approach. Before going on to discuss how economic-environmental IO modelling has developed along these lines, however, it is appropriate to examine Victor’s (1972, p.48) assertion of what he regards as a serious flaw in the Leontief approach:

Leontief ignores the flow of material through the economy and hence neglects the materials balance principle, since he concerns himself only

with the flows from the economy to the environment and not in the reverse direction.

Given what has been argued in this chapter, it would seem that this statement is not strictly correct: what the Leontief approach ignores is the environmental sectors and the extraction of non-marketed natural resources from those sectors. What Victor's (1972) criticism is aimed at is the fact that Leontief (1970) treats pollution simply as a "by-product of regular economic activities" (Leontief 1970, p.262), and focuses on the industrial sources of pollution and assessing the costs of limiting this pollution through pollution abatement technology and/or policy actions. However, I would argue that it is not true that the Leontief approach *ignores* the flow of materials through the economy. Allowing the flow of economic materials (i.e. materials that can command a price) to be tracked through the economy is one of the basic functions of a multi-sectoral approach such as IO modelling. Victor's (1972) argument centres on the *type* of flows that are tracked. That is to say, he is concerned that flows of *natural* materials are neglected. It is certainly true that in Leontief's (1970) basic outline of his approach, because the economy is only disaggregated into two industrial sectors – 'agriculture' and 'manufactures' – the flows of natural materials that are likely to cause pollution are not separately identified. However this is due to the lack of disaggregation in the basic model, not to the approach itself: where sectors that extract, refine and distribute natural resource-based outputs are identified, the causal relationship between these types of material flows and the generation of pollution *can* be modelled. For example, in Leontief & Ford's (1972) empirical model, 90 industrial sectors are identified, including a number which produce natural resource-based commodities – e.g. petroleum refining, lime, crude petrol & natural gas etc. The point is that, with a high level of sectoral disaggregation, the (direct and indirect) use patterns of many different materials inputs (as the outputs of the different sectors identified) and consequent generation of pollution by the different sectors (and households) of the economy can be tracked.

The problem that Victor (1972) seems to have with the Leontief approach is that materials flows are not accounted for *from root*, with extraction from the natural environment. However the reason for Leontief's (1970) omission of the

environmental sectors would seem to have more to do with the problems of data and valuation associated with these sectors that I have discussed above, rather than a simple disregard of the MBP. He does refer to “valuable, but *unpaid-for* natural inputs” (p.262) alongside pollution as being “linked directly to the network of physical relationships that govern the day-to-day operations of our economic system” (p.262). Leontief’s (1970) statement that these links are “too often disregarded” (p.262) implies an awareness of the importance of *both* natural resource extraction and pollution but chooses to focus on the latter because of the problem created by the absence of markets at the start of the causal chain.

Where there are data and valuation problems with modelling the use of natural resources, the solution would then seem to be to focus on *marketed* materials flows. This is most likely why Leontief-type models that do consider the link between input use and pollution usually treat natural inputs as the economic outputs of sectors whose activity is the extraction, refinement and/or supply of natural resource based commodities. By concentrating solely on marketed materials in this way means that, while the materials flow is not strictly modelled from root (i.e. from the point of extraction from the environment), environmental damage (pollution) can be attributed to different intermediate input use patterns, and to the value of sectoral outputs. In other words, much of the sequence of causality implied by the MBP *can* be captured even though the full relationship between the extraction and insertion of materials from and to the environment by the economy is not.

In conclusion, then, I would summarise the development of economic-environmental modelling by saying that, contrary to the criticism that economics has tended to ignore the MBP and its implications, the earliest attempts to model the economic-environmental system in an IO framework were in fact attempts to capture this very thing. However, practical difficulties led to the early focus on the MBP giving way to Leontief’s (1970) more policy-orientated analysis of the environmental repercussions of economic activity in terms of the generation of specific types of pollution, and the costs of eliminating/reducing the generation of these ‘externalities’. Nevertheless, as I will explain in the next section, as economic-environmental IO modelling has

developed, the importance of the causal relationship between the use/consumption of certain types of materials and the generation of pollution has been recognised in addressing specific environmental questions. However, it is important to recognise the key difference between the ‘Victor-type’ MBP approach and the more commonly adopted ‘Leontief-type’ approach. Victor-type models focus on the physical relationship implied by the MBP, by attempting to balance the extractions and insertions of *all* materials from and to environmental sectors (although this approach does not seem to have been successfully adopted in practice). Leontief-type models, on the other hand, tend to be more policy-orientated, focussing on a limited sub-set of marketed materials and specific types of pollution.

5. Survey Of More Recent Economy-Environment IO Models

5.1 The Choice Between Leontief- And Victor-Type Approaches In Recent Economy-Environmental IO Analyses

As I explained in Section 4.3, the most common approach to economic-environmental IO modelling has been to adopt Leontief-type methodology, generalising the standard IO system of the economy with additional rows and columns to take account of environmental factors, rather than attempting to model even part of the environmental system. It may be argued that Victor’s (1972) attempt to model extractions of material resources from, and the return of waste materials to environmental sectors may be more appropriate in materials balance terms, but in practical modelling terms these sectors have proved difficult to quantify. Most of the models reviewed here only attempt to deal with *marketed* flows of natural materials, particularly different types of energy, between *economic sectors*. The resulting flows of waste/pollution tend only to be modelled in terms of the physical amount generated and not the environmental sector (or ‘sink’) which they flow to.

Only one of the models reviewed here, Lange (1998) attempts to model extractions of natural resources directly from the environment. This is a model of the Indonesian economy, one which is heavily dependent on its natural resource base, with most

domestic production activities either directly or indirectly using one of more of the country's key natural resources (land, rainforests and water) intensively. The problem of feedback effects to the environment resulting from the economy's use of natural resources is also considered important because of domestic concerns over air pollution, the availability and quality of water, and soil erosion.

As the environmental component of his IO model, Lange (1998) uses Natural Resource Accounts (NRA) constructed for Indonesia, which are more commonly used for the calculation of sustainability indicator values, rather than being built into a model for full policy analysis. In their full form NRA incorporate both stock and flow accounts and are considered suitable for recording the use, depletion and degradation of natural resources that is associated with economic activity. As such, they could, in principle, be expected to overcome the problems discussed in the previous section with respect to modelling non-marketed flows of materials from the economy to the environment, providing the type of established data sources that Victor (1972) argues are simply not available for the environmental system. However, because of the type of data problems already discussed here, NRA are difficult to construct, and Lange (1998) explains that the accounts constructed for Indonesia are incomplete.

First of all, stock accounts were not constructed, meaning that the effect of flows of materials to and from the economy on the stock of available resources could not be fully examined. Secondly, while physical flow accounts *are* considered to be consistent with the materials balance approach, Lange (1998) explains that in the Indonesian case these were not all-inclusive, instead focussing only on variables that were considered relevant to the country's development strategy. However Lange (1998) does use a variation on Victor's (1972) approach, as described by equations (3.4) and (3.5) above: he does not attempt to define or model environmental *sectors*, but does construct resource-use coefficients for each economic sector as in equation (3.4). In the case of pollution/waste generation, however, rather than using the type of *output*-pollution coefficients constructed by Victor (1972) and Leontief (1970), Lange (1998) links the generation of pollution/environmental degradation directly to

natural resource use. For example, sectoral air pollution coefficients are constructed by multiplying fuel specific emission parameters by the amount of that fuel used by each sector (where the amount of fuel used is determined by the product of fuel specific input coefficients and sectoral output).

Thus, apart from not identifying environmental ‘sectors’, Lange (1998) does attempt to capture the flow of materials to and *from* the environment just as argued for by Victor (1972). However, Lange (1998) does manage to capture the causality between resource use and pollution generation more directly than Victor (1972) did. He does this by constructing the coefficients in matrix B as input to the environment of the pollutant p per unit of *input* of the environmental good r used by each economic sector to produce one unit of output of the economic good i . This is in contrast to Victor (1972), who constructed these coefficients as input to the environment of the pollutant p per unit of *output* of the economic good i . The issue of relating pollution generation to inputs or outputs is not such an important one in terms of the amount of pollution generated in the case of IO (where the input mix is fixed because of the assumption of universal Leontief production relationships the two are essentially equivalent). However where there is interest in tracking the chain of *causality* from the extraction and use of natural resources to the release of pollutants back into the environment it is likely to be more informative to explicitly link pollution generation to input use.

A number of the other IO models reviewed here – Gale (1995), Hyami *et al* (1997) Lenzen (1998) and Weir (1998) - also take the step of relating the generation of pollution directly to input use rather than sectoral outputs. However the key difference is that these models follow the Leontief (1970) approach of modelling *marketed* natural resources, and tend to focus on energy, a category of natural resource for which markets *do* exist (*after* the point of extraction from the environment). Where natural resources such as energy resources are marketed, this means that they can be modelled as economic commodities that are the outputs of economic sectors whose activity is to extract, refine and/or supply energy products. Note, however, that energy flows tend to be converted to physical units in order to

calculate pollution coefficients, since emissions factors for different energy types tend to be given in physical terms. For example, see Weir (1998) who chooses to use energy data in calorific units for the purpose of modelling the link between energy use and emissions of air pollutants. Therefore, the key issue becomes whether the IO data available will allow the appropriate level of sectoral disaggregation to identify flows of energy materials, and the associated waste/pollution generation, through the economy. This question is discussed in more detail in the next section.

One more point worth noting, in terms of the basic approach taken, is that the second pollution issue tackled by Leontief (1970) in his basic (analytical) model - modelling pollution elimination/abatement processes - does not seem to have been widely addressed by modellers who say they adopt a 'Leontief-type' approach. It would seem problems encountered by Leontief & Ford (1972) in identifying 'pollution abatement' sectors (discussed in Section 4.3 above) are indeed difficult to overcome in practice. Only one of the IO models reviewed here, Schäfer & Stahmer (1989), who focus on the problem of modelling pollution abatement as a service carried out by an entirely separate sector of the economy attempts to tackle this issue. However, I reserve further discussion of this model until the next chapter, where I discuss economic-environmental CGE models, since the question of pollution abatement seems to have been more widely addressed in the more general CGE framework than in IO models. In particular, one CGE model, Nestor & Pasurka (1995) actually incorporates Schäfer & Stahmer's (1989) IO table, and their approach is discussed more fully in Chapter 4.

5.2 Sectoral Disaggregation

In Section 2 I explained that one of the necessary characteristics of a model of economic-environmental interaction is that such a model should be multi-sectoral in nature because of the importance of the composition of economic activity in determining its environmental impact. I have argued that this is the case because resource use and pollution generation characteristics are likely to vary significantly between different industrial sectors, as well as between (and within) different

categories of final demand (for example between different types of household, or between households and tourists). This is one of the key reasons why a general equilibrium approach is normally taken to be appropriate where economic-environmental interactions are likely to be important, because of the focus on the microstructure of the economy.

Typically general equilibrium models are built using a set of IO accounts (as I have argued in Section 4.2 above this does not imply an IO *model*). Creating an IO database is, however, a highly resource intensive task, but one that is mitigated by the fact that IO accounts are routinely constructed nowadays for most industrialised countries as part of national accounting. (Though, as I will explain in Chapter 6, this is likely to be more of a problem at the sub-national level – i.e. if a model is being constructed for a regional economy.) All the IO models that I review here have been developed using such a database. However, while standard IO tables do tend to have very high levels of sectoral disaggregation, several of the authors whose models are reviewed here cite ‘over-aggregation’ of their database as a key problem both in model construction and analysis using the model. Hawdon & Pearson (1995) explain that, because IO tables are not normally designed with the main purpose of exploring energy-environment questions, the sectoral classifications may be inappropriate, often over-aggregating important energy sectors and industries with significantly different pollution characteristics. Lenzen (1998) and Gale (1995) both cite over-aggregation as a principle shortcoming of their analyses, with respect to fuel-use and electricity sector data respectively. Lange (1998) also raises the issue of IO sectoral classifications being compatible with environmental concerns, particularly if the modeller wants to use an MBP approach, which would require a very high level of disaggregation. Therefore there may be a need for further, often extensive, disaggregation of existing IO tables, a process which is likely to have significant cost implications or rely on assumptions as to how an existing sector should be further disaggregated¹⁷.

¹⁷ Take for example how Gale (1995) had to use assumptions based on foreign data in order to disaggregate the Mexican electricity sector.

Therefore, I would argue that the main issue is not so much about the number of sectors identified, rather the question is *what* sectors the model identifies. There are two key factors to be considered:

1. *Identifying sectors that supply the resource types that the modeller wants to include as intermediate inputs/consumption goods and/or which supply resources with distinctive pollution characteristics.* Where energy is the key resource type it is common to at least include coal, gas, electricity and oil sectors – e.g. McNicoll & Blackmore (1993). However several of the models reviewed here argue that this is still an over-aggregation – e.g. Gale (1995) argues that hydroelectric power should be distinguished because its use has differential pollution characteristics compared to other types of electric power. Another point of distinction raised in several of the models here is identification of different stages of energy supply – e.g. Hawdon & Pearson (1995) identify both oil extraction and oil processing and Gale (1995) identifies electricity generation and distribution.
2. *Identifying sectors that have different resource use/consumption patterns.* The models reviewed here generally distinguish between agriculture, manufacturing, transport, construction and services, with most further disaggregating these sectors to varying levels of detail. Most of the models also distinguish between different categories of final demand, at a minimum recognising public and private consumption (Östblom, 1998), and at the greatest level of detail identifying different types of household (Hawdon & Pearson, 1995, and Labandeira & Labeaga (1999)).

5.3 Accounting For Different Types Of Pollution Generation

In terms of what types of pollutants are modelled, I find that this varies with the focus of the model. However most of the IO models reviewed here - Gale (1995), Hawdon & Pearson (1995), Hyami *et al* (1997), Lange (1998), Lenzen (1998), Östblom (1998) and Weir (1998) - focus on emissions of air pollutants that are

classified as greenhouse gases. Gale (1995) only models a sole pollutant, CO₂, while the others also include other greenhouse gases that are considered to be important to the economy in question. McNicoll & Blackmore (1993) is the only IO model reviewed here that does not focus solely on greenhouse gas emissions, modelling a wider range of pollutants (twelve in total), which are likely to be of more local concern (as opposed to the more global nature of concern over greenhouse gas emissions).

Another issue that I have already touched upon above is the question of whether pollution is related to inputs or outputs. The simplest and most basic way to model pollution in an IO model is the approach adopted by Leontief (1970) and Victor (1972): augmenting the standard model with a matrix of output-pollution coefficients for each sector of the economy. As I have noted above, in terms of modelling the amount of pollution generated by any given economic activity, the distinction between input- and output-pollution coefficients is not an important one in the case of IO. This is because the assumption of universal fixed (Leontief) production technology means that there is a constant proportional relationship between inputs and outputs: with the input mix fixed, output-pollution coefficients will be equivalent to input-pollution coefficients in terms of impact. However I also make the point that, where IO is being used for such descriptive analysis as tracking the relationship between natural resource use and pollution generation, linking pollution to resource inputs would more directly capture the causal relationships that exist.

Weir (1998) highlights another motivation for modelling input-pollution relationships in an IO framework. This model was built for a study that involved looking at the relationship between energy consumption patterns/alternative technologies and emissions of pollution in the Danish economy over several time periods (a comparative static analysis). Therefore, Weir's (1998) study was concerned with examining the chain of causality between natural resource (energy) use and the generation of pollution, making it worthwhile to model the direct relationship between input use and pollution. However, given that Weir (1998) is a historical study (based on actual energy use data) the input-pollution coefficient

approach is more suitable because the fuel mix used and energy intensity of production over the study period is known to have changed. In other words, although this is an input-output study, Weir (1998) makes off-line adjustments to the input mix according to the historical data. In this type of case constant output-pollution coefficients would *not* give numerically equivalent results for the amount of pollution generated.

Therefore, there are important reasons why it may be desirable to model input- rather than output-pollution relationships in an IO framework, even though the assumption of Leontief technology means that, by definition, the two methods will give the same results in terms of the amounts of pollution generated. However, most IO models still incorporate pollution generation in the basic manner proposed by Leontief (1970) by extending the IO tables with an extra row for the output of each pollutant. This means that, by carrying over the assumption of linearity to the relationship between each sector's output and the quantity of pollutant emitted, (constant) coefficients of pollutant per unit of output can be derived. This remains the most popular approach to modelling pollution in an IO framework; of the models reviewed here McNicoll & Blackmore (1993), Hawdon & Pearson (1995), and Östblom (1998) all adopt the standard Leontief approach.

However McNicoll & Blackmore (1993) do discuss construction of a model where sectoral emissions of each pollutant are based on fuel use. They explain that emissions would then be calculated as the product of a pollution emissions factor, denoting the volume of the pollutant in question per unit of each of the fuel types, and the volume of each fuel used by the sector. However in the actual model constructed, McNicoll & Blackmore (1993) opt for an approach involving "compilation of actual total sectoral outputs of pollutants, which can then be related to sectoral gross outputs" (p.43), over one involving "application of appropriate pollution emission coefficients to appropriate inputs, especially fuels" (p.43). They explain that this choice was made on the basis that the former approach was better suited to the data available at the time of model construction.

Gale (1995), Lenzen (1998) and Weir (1998) are the only IO models reviewed here that employ an approach based on modelling the relationship between inputs and pollution generation. Lenzen (1998) focuses on CO₂ (and other greenhouse gas) emissions resulting from the combustion of fossil fuels, which are calculated by combining the matrices of industrial and household consumption of different fuel types (explained above) with a vector of CO₂ contents per energy unit of combusted fuel. Gale (1995), who only models CO₂ pollution, models emissions as the product of the fuel use vector (giving fossil fuel use in production for three fuel types) for each sector and a vector giving the quantity of CO₂ emissions per unit of each type of fuel. However this model also includes modelling of output-pollution relationships in the case of non-fossil fuel (non-combustion) sources of CO₂ emissions, mainly because of the prevalence of activities such as brick, tile, cement and glass production which give rise to this type of emissions in the economy in question (Mexico). Weir (1998) does not include non-combustion emissions, but models three pollutants – CO₂, SO₂ and NO_x – with the implication that the information requirements are increased, especially given that emissions of pollutants like SO₂ and NO_x accompanying fuel use vary significantly according to the combustion technology used.

One thing that is apparent from reviewing these studies is that modelling input-pollution relationships appears to have considerably heavier data and computational requirements than the simpler approach of assuming a fixed, constant proportions relationship between sectoral output and total emissions of each pollutant. However, as I explain in Chapter 6 (where I discuss the construction of an environmental IO system for Jersey), if we want to construct economy-specific *output*-pollution coefficients, and pre-existing environmental accounts giving total emissions of each pollutant by each IO sector are not available, the information requirements are the same. This is because the total emissions generated in the production of output still heavily depend on the input mix used.

5.4 Accounting For Consumption Behaviour

One of the key advantages of using an IO framework to analyse economic-environmental interactions is that it captures both direct and indirect resource use and pollution generation requirements embodied in final consumption. Clearly it is important to be able to quantify indirect consumption of polluting resources (through purchases of goods and services from industrial sectors that have entailed resource-use and pollution generation in their production), because this facilitates analysis of the demand patterns that drive pollution generation in the economy. However several authors have pointed out the importance of accounting for the *direct* use of natural resources and generation of pollution by final consumers. This is considered especially important in the case of energy use by households, which are likely to use significant amounts of polluting energy resources directly for activities such as heating their homes and running their cars.

Luptacik & Böhm (1999), in an article on using the Leontief approach to modelling pollution generation, suggest an extension of research to address the question of pollution generated by consumers as well as by producers (i.e. direct pollution generation by households). Östblom (1998) cites this point in explaining his motivation for modelling of directly consumption generated pollution by households (such as from the combustion of motor fuels) and the public sector along with industrial output of pollution. However Luptacik & Böhm's (1999) suggestion appears to have been pre-empted by several of the IO models reviewed here: Gale (1995), Lenzen (1998) and Weir (1998), all account for emissions resulting from fuel use by final demand categories as well as by production sectors.

For example, Lenzen (1998) examines both direct and indirect energy-use in the Australian economy. His results from breaking down the total primary energy requirements into final consumption categories highlight the importance of identifying direct and indirect energy consumption by households. Indirect energy use by households (via household purchases of goods and services which have embodied energy consumption in their production) accounts for the most significant proportion (40%) of total primary energy requirements in the Australian economy. Direct energy use by households (via consumption of electricity and household fuels,

and private car use) is less important but still very significant, accounting for 21% of the total. Government final consumption accounts for a further 11% of total primary energy requirements. The remainder of the total primary energy requirements of the Australian economy is accounted for by exports. Energy requirements met from imports are included in these figures, amounting to 24% of the total. Note, however, that Lenzen (1998) emphasises the problems involved in employing the simplifying assumption of equal energy (and emissions) intensities in domestic and foreign production.

Of course, the corollary of primary energy use, particularly where this involves consumption of fossil fuels, is pollution generation. Along with his breakdown of total primary energy requirements into Australian final consumption categories, Lenzen (1998) examines the breakdown of total greenhouse gas requirements by final consumption categories. As in the case of energy requirements, he finds that the sum of direct and indirect greenhouse gas requirements to meet final demand by the household sector accounts for most of the greenhouse gas requirements in the economy (58%). This result emphasises the importance of focussing on consumption rather than simply production-generated pollution. While Lenzen (1998) finds that the majority of greenhouse gas requirements for household consumption are indirect, through purchases of produced goods and services, the proportion required for direct consumption is still significant, at 11% of the total greenhouse gas requirement of the economy.

However, one other important question in terms of the environmental impact of consumer/household behaviour is the differential impact of different *types* of consumer/household. For example does the environmental impact of consumption behaviour differ according to income? One very important question, in terms of 'sustainability policy' is the distribution of income. Are the costs imposed by environmental policy borne evenly by households on different levels of income, and equitably in terms of which households are most responsible for environmental damage? For example, it could be argued that households on higher incomes will indulge in more environmentally harmful behaviour, such as lighting and heating a

larger home, or keeping a couple of cars on the road. However any tax on energy use is likely to be felt harder by lower income households, since energy costs will take up a larger proportion of their income, or by households in remote locations whose demand for motor fuels are relatively price inelastic.

I would argue that, in order to address questions like these, household disaggregation may be as important as disaggregation of industrial sectors in order to account for and model differential energy demand characteristics. However only two of the IO models reviewed here identify different types of households: the first is Hawdon & Pearson (1995), who disaggregate households by income groups. They also use (UK) Family Expenditure Survey data used to split total consumers' expenditure between income groups and industrial sector outputs. They explain that this means that the matrix of pollution coefficients per unit value of personal consumption could be disaggregated "to distinguish between the effects of the consumption activities of different social groups" (Hawdon & Pearson, 1995, p.80). (They identify two income groups, 'upper' and 'lower'.) The other study that models different types of household is Labandeira & Labeaga (1999), where households are disaggregated into different expenditure and demographic groups. This is a short-run study: the authors state that they focus on household *expenditure* to examine distributional effects because they do not consider short-run income to be a reliable indicator of household welfare.

6. Chapter Summary And Conclusions

The focus of this chapter is an examination of the question of modelling economic-environmental interaction and interdependence. In Section 2 I consider the necessary requirements of an economic-environmental modelling framework. In Section 3 I identify multisectoral general equilibrium modelling as an appropriate framework for modelling economic-environmental interactions, with IO distinguished as a limiting case of more general CGE modelling.

Then in Section 4, I examine some early attempts at modelling economic-environmental interaction. I explain that these focus on capturing the implications of the mass or materials balance principle (MBP) in a fully-integrated model of the economic-environmental system. However I reach the conclusion that not only are the data requirements involved in modelling the entire economic-environmental system prohibitive, but a more fundamental problem exists in the fact that in practice most economic-environmental models are constructed for sub-global regions. Thus I argue that modelling the full economic-environmental system for sub-global economies is both an impractical and an inappropriate approach. Moreover, given the universal fixed coefficients perspective of IO, I reach the conclusion that, even where the economy being modelled is the global one, the importance of finite stocks in the environmental system would mean that modelling the entire economic-environmental system is an inappropriate development. I also raise the question as to whether a demand-driven system such as IO would be appropriate in the first place due to the fact natural resource provision is likely to be dominated by environmental supply-side factors.

The most popular approach to economic-environmental IO modelling, first initiated by Leontief (1970) is introduced in Section 4.3 as offering a practical (if imperfect) way forward. Section 5 of the chapter is then devoted to examining more recent examples of economic-environmental IO modelling. One important development discussed in this section is the focus of several authors on modelling input-pollution relationships instead of, or as well as, the traditional Leontief approach of modelling the relationship between sectoral output and pollution in order to track the relationship between resource use and pollution generation. This can also be considered an important development where it is felt there is a need to generalise to a more flexible CGE framework in order to address some common environmental issues, a point that I return to below.

Generally, the main advantages of using the IO approach for analysing environmental questions are widely accepted, but not really related to the MBP notion which earlier attempts at modelling the economic-environmental system, such

as Isard (1969) and Victor (1972), were clearly aiming to capture. Rather the recognised advantages of IO tend to focus on the level of detail on interdependencies and interactions within the economy and between the economy and the environment through relatively high levels of sectoral disaggregation and the clear causal ordering of both direct and indirect resource use and pollution generation.

The latter is cited as the main strength of the approach in a number of the studies reviewed here. For example Lenzen (1998) adopts IO methodology because of the importance of indirect energy use, many goods and services purchased from industry sectors having entailed resource-use and GHG emissions in their production. The focus of the paper is primary energy and GHGs embodied in Australian final consumption, highlighting the importance of emissions attributable to a country's *final consumption* rather than its production. This is because imports may embody resource-use and pollution in the exporting country, a point that is relevant because of the global nature of the global warming and sustainability problems - i.e. attributing resource depletion/pollution to the country where it eventually goes to support final demand.

This issue alone is seen as providing an important application of IO. In measuring sustainable income and calculating sustainability indicators for individual countries, the extent to which countries are reliant on imports of natural resources, and/or imports that have entailed resource-use/pollution in their production, is important. Atkinson *et al* (1997) and Pearce & Atkinson (1995) discuss the misconception of 'importing sustainability', where a country may appear to be behaving sustainably, but global sustainability is in fact threatened when the environmental ramifications of its imports are fully accounted for. Therefore, just as IO analysis of individual economies allows resource-use and pollution to be attributed on the basis of both direct and indirect consumption, in an international setting IO can be used to attribute resource depletion and pollution to the country where it eventually goes to support final demand. This would require the type of multi-regional IO framework that is not very common in the literature. However such a framework would facilitate fuller exploration of the environmental costs attributable to any one country's consumption

behaviour rather than the allocation of responsibility for resource use and pollution generation arising in its production activities that is possible using a single economy environmental IO system.

Therefore, I come to the conclusion that IO provides a useful framework for tracking direct, indirect and induced energy-use and the consequent generation of pollution in an economy. In the context of the policy proposals examined in Chapter 2 for use of 'sustainability indicators', this means that IO modelling has much to offer in descriptive terms, because it allows determination of demand patterns in the economy which give rise to observed levels of resource use and pollution generation.

However, I would argue that there is an important disadvantage associated with conventional IO techniques, which means there might often be a need for a more flexible CGE framework. With its assumptions of constant technical relationships and passive supply-side, the range of effects and disturbances that can be modelled within a conventional IO framework is limited. Other types of effect must be calculated 'off-line', on an *ad hoc* basis, by the modeller, then fed back into the model. For example, Hawdon & Pearson (1995) argue that their model can be used to simulate the effects of changes not only in exogenous variables (final demand, income taxes and transfers) but also through changes in the structural matrices and their coefficients. However on the latter they describe how this involves working off-line: in changing the structure of electricity, by introducing more gas power generation at the expense of coal to reduce emissions, the coefficients in the electricity column of the input-output coefficients matrix must be changed. However this unbalances the matrix, and it is necessary to make compensating changes to ensure that impacts on the rest of the economy come from changes in the composition of inputs rather than from changes in total input requirements. Moreover, the emissions coefficients for electricity have to be changed to allow for the changed average pollutant output effect resulting from changes in the input structure.

Weir's (1998) 'structural decomposition analysis' also involves this type of 'off-line' calculation, changing factors such as IO coefficients, emissions factors and energy intensities "one by one to quantify the contribution of each component to the total changes in emissions" (p.105). Note that Weir's study involves historical IO matrices – i.e. changes that actually occurred. However, care should be taken if changes are *ad hoc* ones specified by the modeller. The ability to make such changes directly and explicitly (without having to specify a cause), and thereby isolating the effects of changing one factor, may be technically correct (and indeed seen by some as an advantage of IO over more general CGE – see Ayres, 1995). However, it seems questionable from an economics viewpoint. Is it reasonable to use the *ceteris paribus* assumption of all other factors being held constant? For example, using a CGE model, Beauséjour *et al* (1995) use a fossil fuel tax to simulate the effects of the imposition of such a tax on CO₂ emissions and find that emissions of other pollutants are simultaneously affected despite policy only being aimed at CO₂. Such additional effects would have been missed in an IO analysis where the pollution coefficients are directly changed one at a time. The point of using a general equilibrium framework is to understand the importance of interdependencies in the economy (and with the environment). If one factor changes there are likely to be knock-on effects within the system because of these interdependencies.

For all these reasons, my argument is that it is important to take care in deciding when it is appropriate to use an IO approach. In particular, there are two inter-related sets of circumstances where IO will not be a suitable approach:

1. *Where a disturbance to the system is likely to change relative prices.*
Conventional IO models cannot capture price-induced substitution effects because all functional relationships are of the Leontief (constant proportions) form – i.e. all inputs to production and consumption goods are modelled as perfect complements. That is to say, there are no possibilities for substitution in response to a change in relative prices. This is likely to be an important limitation where substitution between inputs with different pollution intensities is possible in response to (often policy-induced) changes in relative prices.

2. *Where supply-side effects are likely to be important.* Because of the assumptions of a passive supply-side, conventional IO techniques are not suitable for modelling situations where there may be supply constraints or where supply-side disturbances (including policies) may be important¹⁸.

Where one or both of these factors is likely to be important, it would be more suitable to use a CGE framework, which can incorporate more flexible behavioural relationships and a more realistic model of the supply-side of the economy. My next step, therefore, is to go on to look at more flexible CGE frameworks that are capable of modelling a wider range of problems.

¹⁸ It has been argued (Ghosh, 1958) that it is possible to construct a supply-driven IO system. However the problem still remains that supply and demand cannot be determined *simultaneously* using IO techniques (moreover, the Ghoshian approach has been the subject of severe criticism – see Oosterhaven, 1988, 1989).

Chapter 4. Economic-Environmental CGE Modelling

1. Introduction

My main conclusion at the end of Chapter 3 was that, while providing a useful framework for tracking direct, indirect and induced energy-use and the consequent generation of pollution in an economy, IO is likely be too restrictive a framework for *modelling* the impacts of policy changes and other disturbances. The more flexible type of CGE modelling that I examine in this chapter can be regarded as extending or generalising empirical fixed input-output coefficient general equilibrium models by incorporating substitution effects in both production and demand through price-endogeneity (Shoven & Whalley, 1984). However, the critical point in moving from IO to CGE is the incorporation of an active supply-side as well as the demand side of the economy, so that relative prices and quantities are determined endogenously and supply and demand in all markets are equilibrated simultaneously.

My objective in this chapter is to identify the general issues that are likely to be important in constructing an economic-environmental CGE model for a small open regional economy like Jersey. A comprehensive review of the literature, examining *all* issues that are relevant to a CGE modelling project, is outwith the scope of this dissertation. Instead, I focus on issues that are specific, or at least especially relevant to the case of *environmental* CGE modelling. This involves my reviewing the current literature in order to examine how existing CGE models deal with questions of natural resource use, pollution and income distribution, the three factors that I have identified in Chapter 2 as key dimensions of pursuing a goal of sustainability.

The first issue that I address in this chapter, in Section 2, is a key one in terms of modelling with the stated objective of ‘sustainable development’: geographical/spatial focus and the ‘small open economy’ assumption. In Section 3 I examine the issues associated with introducing natural resource inputs, particularly energy, on the production side of the economy, alongside the standard capital, labour and material inputs. In Section 4 I then go on to survey how the introduction of

energy and natural resources as factors of production has been addressed in existing models. In Section 5 I examine the main issues involved in modelling the generation of pollution as a result of economic activity in general, and natural resource use in particular. I turn my attention to issues involved in modelling consumer behaviour in an economic-environmental context in Section 6. In particular, I look at one question that is particularly relevant to the topic of sustainability: the possibility of modelling the distributional impacts of disturbances, such as environmental policy, as well as the environmental effects of differential consumption patterns across different types of households. Finally I provide a summary and conclusions in Section 7.

2. Geographical/Spatial Focus

All of the IO models that I have reviewed in Chapter 3 are models of single regions/countries. This is not the case with the CGE models reviewed in this section, a number of which are global models, and/or inter-region/country models. In terms of the former, use of environmental CGE models seems to have become a popular approach to examining the economic causes of the global climate change (global warming) problem. This is illustrated by the prevalence of CGE models in the OECD comparative modelling project (reported in Dean & Hoeller, 1992) on assessing the costs of reducing CO₂ emissions. The three global CGE models that I review here were included in this project. These are the GREEN model (Burniaux *et al*, 1992), the Carbon Rights Trade Model, or CRTM (Rutherford, 1992), and the Whalley-Wigle Model (Whalley & Wigle, 1992). The approach of these global CGE models is to divide the world into a number of regions (they are essentially inter-regional models), with groups of countries being treated as regions of the global economy. However, given that the specific focus of my dissertation is modelling a small open economy as an individual region, the multi-country focus of many contributors is of limited interest.

In Chapter 1 (Section 2) I explained that the ‘small open economy assumption’ is of key importance in the present study. When this assumption is made it implies that *the rest of the world is taken to be exogenous*, so that only the economy under

consideration is modelled. The ‘small open economy’ does interact with the rest of the world, via trade, but its activity is assumed to have no significant impact on the rest of the world. This means that any spillover effects from the target economy to the rest of the world are trivial, given the scale of the rest of the world, which in turn implies that there are no significant feedback effects from the rest of the world to the target economy.

In Chapter 1 I also explained that the key point of making the small open economy assumption in the context of economic-*environmental* modelling is that the global environmental impact of the target region’s economic activity is taken to be trivial. Thus, it can be assumed that there are no feedback effects from the global environment to the local economy arising from disturbances in the latter. In other words, the contribution from a small open economy like Jersey to, for example, the problem of climate change, is taken to be so trivial that we would not expect economic activity in Jersey to lead to significant climate change effects on the Island through this mechanism. Such environmental feedback effects cannot be handled in a model of a small individual country or region (any environmental impact from the rest of the world on the local economy would have to be handled exogenously). The implication of this is that while a model of the type being constructed here can be used to assess the costs to the local economy of tackling global environmental problems, any resultant benefits of an improved global environment for that economy cannot be assessed. In effect I am assuming that there will be no environmental benefits to the local economy from its individual policy actions aimed at global problems such as climate change. Considering that any beneficial feedback effects would be expected to be very small, this is likely to be consistent with the concerns of the local population and policymakers (this is the public goods problem inherent in tackling global environmental problems)¹.

Nonetheless, lessons can still be learned from global models and other inter-regional models (as well as from models of larger economies that may not be treated using the

¹ The point is that other countries feel most of the benefits derived from Jersey lowering its domestic emissions of greenhouse gases because climate change affects everyone. However, the benefit to Jersey of being part of a successful global environmental policy might be large.

small open economy assumption) in terms of how to incorporate natural resource use and pollution into models of economic systems. However, given what I have said above, global models would be expected to focus on different types of environmental issues than those addressed by single country/region models. The global models that I review here focus on the type of global-system-sustainability concern identified in Chapter 2: as I note above, the particular focus of the OECD modelling project was CO₂ emissions, which are regarded as the key factor contributing to global climate change. Greenhouse gas emissions resulting from economic activity are also a common concern of more locally focussed national and regional models. However, even in the case of modelling larger countries or groups of countries, this tends to be more in terms of *constraints on economic activity* resulting from commitments by individual economies to limit their share of global emissions – i.e. the *local economic costs* of pursuing global sustainability policies.

Individual country/region models are also more likely to be concerned with how pollution affects the local environment and the *quality of life* in the locality. For example, traffic emissions will affect air quality in the areas where people live and work. This is likely to be of more direct concern to the local population than the threat of global warming, over which it effectively has no control or influence. Local pollution problems are therefore more likely to be the focus of a national/regional model constructed for the purpose of offering guidance to local policymakers. Locally-focussed modelling is also more likely to involve a wider range of pollutants which affect the quality of life in local environments, in comparison to global modelling which naturally focuses more narrowly on the greenhouse gases that are a major threat to the global system.

Similarly, global models like GREEN and CRTM focus on the problem of depleting non-renewable natural resources, through inclusion of sub-models of resource depletion, specifically fossil fuels, as part of their dynamic structure. Again, fossil fuel depletion, like global warming, is what I refer to in Chapter 2 as a global-system-sustainability concern, and one that has little meaning at the level of individual countries and regions, since such resources can be imported from

elsewhere in the world. The issue of endogenous fossil fuel depletion is only likely to be a concern in non-global models if the country in question is a “producer” of fossil fuels (for non-producers, the effects of depletion will be transmitted through changes in exogenous prices). It may also be an issue in the form of a self-imposed constraint as individual regions or countries attempt to ‘do their bit’ in conserving global resources, and/or to limit the emission of pollutants resulting from their use. More locally-focussed models may, however, be more directly concerned with questions of resource depletion where the natural resources in question are of the type that cannot easily be imported, such as fish stocks (if the economy in question is significantly dependent on fishing industries) or, more commonly, land.

However, as I have stated above, the common problem for all models, whatever their geographical focus, is how to incorporate an economy’s consumption of natural resources, particularly energy, and the resulting generation of pollutants, into a CGE model of an economic system. In this sense it is useful to draw on a wide variety of models, and this is the purpose of the following two sections on modelling energy use (Sections 3 and 4) and pollution generation (Section 5).

3. Issues Involved In Modelling Energy Use In Production

In a survey of general equilibrium approaches to energy modelling, Bergman (1988) identifies the crucial factor in determining the system-wide effects of changes in energy supply and demand as the elasticity of substitution between energy and other factors of production. He goes on to argue that this finding suggests that the representation of the substitutability of energy between other factors of production is one of the most basic issues that has to be addressed in energy-economy modelling. My review of the literature on modelling energy before and since Bergman’s (1988) survey demonstrates that this continues to be the key issue. A particular source of controversy is whether energy and other factors of production are in fact substitutes or complements, and whether this varies between the short and long run. This leads to the following question: if substitutability between factors is variable over time, how should the relationships between them be represented? Therefore I discuss the

main issues associated with modelling production relationships involving energy use in Sections 3.1 and 3.2. In Section 4 I examine how substitution between energy and other factors of production, and between different energy types have been modelled in the studies reviewed here. I find that the key questions for modelling energy-environment interactions that arise from the discussion in Sections 3 and 4 are:

- What is the best way to model the production structure so that, where appropriate, it can cope with the reality of multiple inputs and elasticities of substitution that differ over types of input, as well as between different sectors and over time?
- What *types* of energy input should be modelled to capture a full range of general equilibrium effects, including the pollution effects of different input choices and/or the response to environmental policies to reduce pollution? (since some inputs will be more polluting than others). This question ties into the discussion in Section 5.2 of another important issue: whether it is better to model the relationship between sectoral outputs and pollution, or between inputs and pollution, or both².
- How important is the country-specific context and institutional setting for which the model is being built? The economic, social and policy conditions present in the particular country/region being modelled will influence how the model is built. This question is also important in terms of modelling pollution, as I will explain in Section 5.
- Another issue that is considered important in terms of both energy use, and the subsequent generation of pollution, is one that I have already identified in Chapter 3 (environmental IO models). This is the issue of modelling of both direct and indirect energy consumption and pollution generation by households

² This issue has already been raised in Chapter 3, Section 5.1, with respect to accounting for and modelling pollution generation in an IO framework.

and other final consumers, and one that I address in Section 6, where the general issue of modelling consumer behaviour is examined.

3.1 Modelling Production Relationships Involving Energy Use

The most common approach to modelling production relationships in CGE models generally involves using nested production functions involving a hierarchy of Constant Elasticity of Substitution (CES), as well as Cobb-Douglas (CD) and/or Leontief (where appropriate), relationships between different inputs. The motivation for using CES forms is that they permit more flexibility than CD, where the elasticity of substitution must be equal to unity, and Leontief, where the elasticity of substitution is equal to zero (i.e. no substitutability at all - fixed factor proportions). However the flexibility offered by the CES functional form is limited:

- (a) The name ‘constant elasticity of substitution’ derives from the fact that using CES means employing a production function where the elasticity of substitution is the same regardless of factor proportions and scale (i.e. a constant elasticity of substitution all along the slope of each and every isoquant).
- (b) For *any one* CES relationship, the elasticity of substitution must be the same among all factors. This problem can be overcome by nesting a series of CES relationships within a hierarchical structure. However this requires imposing a set of *separability* assumptions.

The key problem associated with using CES production functions, then, is the specification with a single elasticity parameter, ρ , for all inputs aggregated in a single function:

$$(4.1) \quad Q = A(\sum_{i=1}^N \delta_i X_i^\rho)^{1/\rho}$$

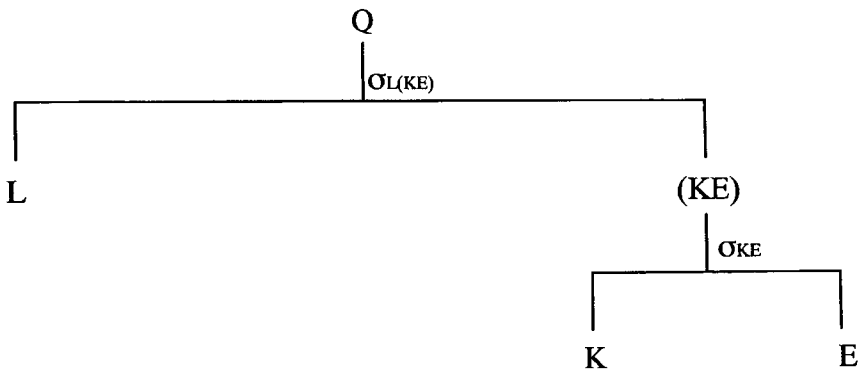
Where A is the efficiency parameter ($A > 0$) describing the state of technology, δ is the distribution parameter ($\delta_1 + \dots + \delta_n = 1$, where $\delta_i \geq 0$) describing relative factor shares

in Q , and ρ is the substitution parameter ($-1 < \rho \neq 0$) which determines the (constant) elasticity of substitution, σ :

$$(4.2) \qquad \sigma = \frac{1}{\rho + 1}$$

Equations (4.1) and (4.2) imply that the elasticity of substitution, σ , between any pair of inputs to the production function must be the same. For example, if there are capital, labour and energy inputs, the elasticity of substitution for capital/labour, capital/energy and energy/labour combinations must be the same. However, as noted in point (b) above, this property can be avoided by nesting a series of CES relationships within a hierarchical structure. For example, in the three-input case of capital, labour and energy inputs, this may look like Figure 4.1 below:

Figure 4.1 – Example Of A CES Hierarchical/Nested Production Function



Using a hierarchical production function such as this one means that the elasticity of substitution between inputs, usually pairs, combined in different nests (levels) can be different; i.e. the value of $\sigma_{L(KE)}$ can differ from that of σ_{KE} . Moreover, the relationships specified in the various nests need not all be of CES form: CD and/or Leontief relationships can be specified at different levels between different pairs of inputs, where appropriate.

However it can be argued that this type of nested production structure is still too inflexible because of the imposition of *separability* among the inputs. This separability argument is concerned with the fact that, in employing nested production structures to allow differing substitutability overall where there are more than two inputs to production, CES/CD production functions usually only allow substitutions between *pairs of inputs* at any level in the hierarchy³. One of these inputs may involve a composite input resulting from substitution between another pair of inputs at a lower level (for example, in Figure 4.1 this is the case with the composite capital-energy, KE, input). This has the implication that both of the inputs incorporated in the aggregate must substitute equally well for the third input. In the Figure 4.1 example, where labour substitutes for the capital/energy aggregate, this means that capital and energy must both substitute equally well for labour.

Some authors argue that such separability assumptions may lead to important parts of any factor substitution effect in response to a change in the price of one factor being lost. Specifically, in the context of the Figure 4.1 example, any response of the capital-energy price ratio to a change in the price of labour that is attributable to differences in the relative substitutability of capital or energy for labour will not be captured.

Three of the other models that I review here – Hertel & Mount (1985), Depotakis & Fisher (1988) and Li & Rose (1995) - recognise these problems⁴. Their response is to adopt some type of flexible functional form (FFF) production function. The idea is to make the production function as flexible possible by minimising the number of prior assumptions about its form. The models which use a FFF here work with *cost functions*, as dual to the production function; Depotakis & Fisher (1988) and Li & Rose (1995) both use Generalised Leontief (GL), and Hertel & Mount (1985) use a Translog cost function. This way the production function is derived via the factor demand functions, rather than being directly imposed by the modeller. By duality,

³ Of course it is possible to have more than two inputs at any one level of a nested CES function. However the point is that the form of the CES function is such that the substitutability between all inputs at any one level/nest (i.e. any single CES relationship) must be the same. For this reason, it is usually the case that only two inputs will combine at any one level of a nested CES function.

⁴ Hertel (1988) demonstrates this argument analytically using a 2-sector model with 3 primary factors.

application of Shephard's Lemma (differentiating a cost function with respect to input prices) yields sectoral input demand functions for each factor of production, where the demand for each factor is a function of the relative prices of all other factors. This means that, for each input demand function, the factor substitution responses to relative price changes are captured by a set of partial elasticities of factor substitution between the factor in question and each of the others, and that these can differ across all combinations of inputs. For example, Despotakis & Fisher (1988) use a GL unit cost function for labour, capital and energy for each sector (j):

$$(4.3) \quad C_j = b_{LL}^j WL_j + b_{KK}^j WK_j + b_{EE}^j PDE_j + 2[b_{LK}^j (WL_j/WK_j)^{1/2} + b_{KE}^j (WK_j/PDE_j)^{1/2} + b_{EL}^j (PDE_j/WL_j)^{1/2}]$$

Where WL_j , WK_j and PDE_j are the prices of labour, capital and the energy aggregate to sector j respectively. Application of Shephard's Lemma then yields the sectoral demand for each factor of production as a function of the relative prices of the other factors. For example, in the case of energy the factor demand will be:

$$(4.4) \quad \partial C_j / \partial PDE_j = b_{EE}^j + b_{KE}^j (PDE_j / WK_j)^{1/2} + b_{EL}^j (WL_j / PDE_j)^{1/2}$$

Thus, changes in factor demand are decomposed into own-price (b_{EE}^j) and cross-price (b_{KE}^j and b_{EL}^j) effects for all combinations of inputs (where b_{EE}^j , b_{KE}^j and b_{EL}^j can differ), rather than imposing fixed constant elasticity of substitution parameter values directly on the production function.

Heathfield & Wibe (1987) explain that own- and cross-price elasticities are related to the Allen partial elasticities of technical substitution of the production function via a cost-share parameter. For example, the cross-price elasticity of the demand parameter for capital with respect to a change in the price of energy, b_{EK} , can be written as $S_E A_{KE}$. S_E is the cost share of energy in sector x, and A_{EK} is the Allen partial elasticity of substitution between capital and energy. This means that the price elasticities of factor demand will vary with factor intensity. Thus a constant elasticity

of substitution is not imposed on the production function (i.e. the rate of technical substitution will generally not be constant all along the isoquant).

This implies that the use of a FFF will overcome the problem (a) noted above (imposing an elasticity of substitution which is the same regardless of factor intensity) that is associated with using CES forms *if* the share parameter is observed and allowed to vary in estimation. It is not clear whether this is the case in the FFF models reviewed here. Rather, the main point of the argument put forward in the FFF models concerns point (b) above: the importance of capturing the possibility of differing substitutability (and/or complementarity) both between different pairs of energy inputs and between energy and other non-energy inputs.

In practice, however, this argument over whether to use CES or FFF is likely to boil down to a trade off between flexibility and tractability. In a model with a highly detailed treatment of energy, Naqvi (1998) argues that separability assumptions are necessary from a practical point of view, where there are multiple inputs (131 intermediates and 3 primary in Naqvi's (1998) own model of Pakistan), and/or multiple sectoral outputs. His point would seem to be that, as the number of inputs (and sectors) increases, the question of tractability would begin to outweigh the appeals of flexibility. This is apparent if we look back at the GL cost function and factor demand function (equations (4.3) and (4.4) above) from Despotakis & Fisher's (1988) model. If this model were to incorporate many more inputs the number of variables (and parameters) in the cost function (4.3) and each of the factor demand functions, as in (4.4), as well as the number of factor demand equations would increase rapidly. This would clearly have serious implications for estimating/calibrating the relationships in practice.

In actual fact, Despotakis & Fisher (1988) work with *two* levels of GL cost functions, the second level specifying the individual energy types which combine to form the energy aggregate. Indeed, all the FFF models reviewed in this chapter choose to employ two levels of cost functions, with substitution between KLEM inputs on the first level, then within the energy and/or materials aggregates on the second level.

Therefore I would argue that it is important to note that all the models reviewed here that advocate the employment of FFF to reduce the number of restrictions, including separability, that are imposed on the production function by use of CES are in fact prepared to accept *some* separability assumptions. This highlights an important issue that I return to again later in the present chapter: why is separability acceptable in one case but not the other? *None* of the models reviewed here report on *testing* different separability assumptions (i.e. carrying out model specification tests). Therefore we can only presume that the decision over separability is based on some prior belief or judgement as to the appropriate assumptions to adopt. I would argue, however, that this decision would be better made as the result of actually testing alternative assumptions, where it is practical to do so, a point that I return to presently.

3.2 The Energy-Capital Complementarity Controversy

A more general problem for modelling production relationships involving energy inputs arises from observed variations in the substitutability between energy and capital inputs over time. In particular, some studies have found evidence of complementarity between these two inputs over certain time periods, but of substitutability over others. This, then, leads to the question of how best to capture substitution possibilities that differ over time.

This problem has been a major issue and the source of considerable controversy in energy-economy modelling ever since research began in this area. Field & Berndt (1981) explain how the controversy arose from disparity in the estimates of the elasticity of substitution between energy and capital in early empirical studies. Two of the most widely discussed early studies were Berndt and Wood (1975), who found evidence of energy-capital complementarity, a result which is most commonly interpreted as a short-run relationship, and Griffin & Gregory (1976) who found evidence of substitutability, which is interpreted as a long-run result. Griffin (1981) explains that Berndt & Wood's (1975) results should be interpreted as short-run results because of the static specification and annual (US) time series data employed.

Griffin & Gregory (1976), on the other hand, explain that they use the same translog cost specification, but with a more general data set, consisting of pooled international data for the manufacturing sectors of nine countries, with observations at 5-yearly rather than annual intervals. They argue that they were concerned that annual time series would not (a) pick up points on a long-run cost function, or (b) capture enough variation in relative prices for the chosen translog specification to properly describe the production structure.

Griffin (1981) and Kang & Brown (1981) report in more detail on some of the results of these and other early studies, and attempt to assess and explain a variety of possible reasons for the disparity of results. Without going into too much detail on their discussions, I draw attention to a quite basic but very important point highlighted by Kang & Brown (1981): that when there are more than two inputs, even defining an elasticity is not a straightforward matter. They argue that “Since any definition of elasticities necessarily involves various partial derivatives, there may be infinitely many different definitions depending on the *ceteris paribus* conditions under which the partial derivatives are obtained” (Kang & Brown, 1981, p.81). This obviously leads to problems in comparing different estimates for the ‘elasticity of substitution’ between any two inputs in a multiple input case, not just the controversial energy-capital case.

An even more basic distinction is whether elasticity estimates are estimates of the elasticity of substitution in the production function (i.e. the shape of the isoquant), or of the cross-price elasticity of factor demand. In the former case (assuming cost minimisation and perfectly competitive factor markets) the elasticity of substitution can most simply be defined as the ratio of the proportionate change in factor proportions of two inputs, X_1 and X_2 to the proportionate change in the relative price of those two inputs⁵:

⁵ Note that the elasticity of substitution is defined here for the 2-factor case because in practice a nested CES/CD/Leontief structure will generally be used to allow different elasticities of substitution over different pairs of inputs. However, as noted above, the elasticity can, and has (Allen, 1964) been defined for the general n -factor case, where $n > 2$ this involves deriving a set of *partial elasticities of substitution* for all possible pairwise input combinations (for any given set of prices).

$$(4.5) \quad \sigma_{12} = \frac{\partial(X_1/X_2)/\partial(P_2/P_1)}{(X_1/X_2)/(P_2/P_1)}$$

The elasticity of substitution, σ_{12} , will always be positive, lying anywhere between zero and infinity: if $\sigma_{12} = \infty$ the two inputs are perfect substitutes, and if $\sigma_{12} = 0$ the two inputs are perfect complements. Moreover it is always the case that $\sigma_{12} = \sigma_{21}$ (Chaing, 1984, Heathfield & Wibe, 1987).

The cross-price elasticity of factor demand, on the other hand, is defined as the elasticity of demand for factor 1 with respect a change in the price of factor 2 (with output assumed to be constant):

$$(4.6) \quad E_{21} = (\partial X_1 / \partial P_2) \cdot (P_2 / X_1)$$

The cross price elasticity of factor demand, E_{21} will be positive ($E_{21} > 0$) in the case of substitutes. Where there are more than two factors of production, E_{21} may be negative in the case of complements ($E_{21} < 0$), because the Allen partial elasticity of substitution, unlike the elasticity of substitution as defined in (4.5), can, by definition⁶, be negative. The relationship between the Allen partial elasticities of substitution, A_{12} , and the price elasticity of demand is (for two inputs, X_1 and X_2):

$$(4.7) \quad E_{12} = S_1 \cdot A_{12}$$

Where S_1 is the cost share factor $[(X_1 \cdot P_1) / (\sum_i X_i \cdot P_i)]$. Note that, although $A_{12} = A_{21}$, we will not have $E_{12} = E_{21}$, unless $S_1 = S_2$. (Heathfield & Wibe, 1987). (Note that the own-price elasticity of substitution, E_{11} , will always be non-positive).

Therefore, studies that report negative elasticity values as suggesting that capital and energy are complements are therefore likely to be referring to estimates of the cross price elasticity between capital and energy in cases where there are more than two inputs, and not estimates of the elasticity of substitution itself.

However, even with due care in interpreting results with regard to what is meant by estimates of elasticity and findings of complementarity and/or substitutability, almost twenty years later the debate over the relationship between energy and capital remains unresolved. As I have noted above, Griffin (1981) explains that an important factor is whether elasticity estimates are for short- or long run time frames, and this remains the main factor in explaining observations of both complementarity and substitutability between capital and energy. Griffin's (1981) point was that observations of complementarity should be interpreted as short-run relationships, because "in the short run energy and capital tend to enter the production process in roughly fixed proportions" (Griffin, 1981, p.71). (Note, however, that this implicitly implies the assumption of a *given* utilisation rate for capital.) This is a similar type of argument as one referred to by Depotakis & Fisher (1988). However their point is that energy and capital may be short-run complements because it takes time to replace energy-inefficient equipment. This argument again seems to imply that in the short-run energy inputs per unit of existing machinery tend to be fixed along with capital, meaning that the two will be complements in production. However, in the long run, when new machinery that requires less energy to run can be installed, this relationship will become more flexible, meaning that it will become possible to substitute capital inputs for energy inputs, increasing energy efficiency by lowering the required energy use per unit of output. The implication of this argument is that not only is there a possibility of fixed factors in the short-run, but also of a fixed production technique.

However, I would argue that framing these explanations in terms of the 'short-run' and 'long-run' is somewhat vague. What is actually important is the status of the factors of production and of technology, rather than time periods as such. If the problem is approached in this way some interesting theories have been proposed to explain differing substitutability over time, one being the so-called 'putty-clay' argument relating to capital stocks. An important point to note in the argument cited by Depotakis & Fisher (1988) is that in the long-run the new machinery that can be

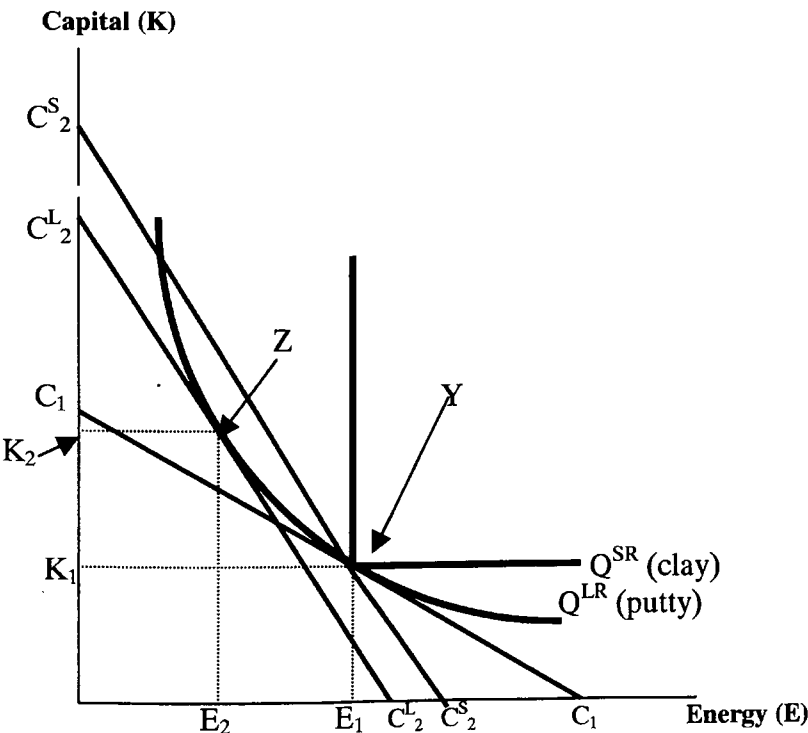
⁶ See Allen (1964, p.504/5).

installed is *different* from the original machinery in that it requires less energy to run. This means that there is also the suggestion of capital heterogeneity to consider, as well as whether capital and the chosen production technique are fixed or variable. Under these circumstances, the putty-clay argument offers what would seem to be a more plausible explanation for the observed variation in the relationship between energy and capital over time than simply discussing conceptual time periods.

The ‘putty-clay’ explanation for differing substitutability between capital and energy over time

The putty-clay argument is based on the idea that when capital is new, it is malleable (like putty), meaning firms can choose how to employ it along with other inputs, such as energy and labour, to produce output. However, once capital has been installed and the input mix is set, substitution decisions over capital become limited (it becomes non-malleable, like clay). This is illustrated in Figure 4.2 where the isoquant becomes more sharply curved as substitution possibilities decline once capital is installed.

Figure 4.2 – Putty-Clay Technology And Energy-Capital Complementarity



The putty-clay story, as illustrated in Figure 4.2, can be used to explain results that suggest short-run complementarity but long-run substitutability between capital and energy. The initial (long run) equilibrium in Figure 4.2 is shown as point Y, where the isoquant Q^{LR} is tangent to the isocost C_1C_1 with the capital-energy input mix, (E_1, K_1) . Now suppose the price of energy rose relative to that of capital, giving the steeper isocost $C_2^S C_2^S$. In the short-run production technology is fixed, characterised by 'old' capital installed in previous periods, which is like clay. This means that energy must be used in fixed proportions with capital to produce output Q. Thus, in the short-run, the production relationship is characterised by the Leontief isoquant, Q^{SR} . Under cost minimisation, the firm would produce where this isoquant is tangent to the new isocost $C_2^S C_2^S$, representing the new relative price of energy and capital. This is the limiting case, where the post-installation decision over how to combine capital and energy means choosing a single point, Y, from the initial range of possibilities for producing output Q.

However, over time 'new' capital is likely to result from investment, thereby increasing substitution possibilities, particularly if, as in the argument cited by Depotakis & Fisher (1988), the new capital is more energy-efficient. As possibilities for substitution between energy and capital are introduced ($\sigma_{EK} > 0$), the isoquant characterising production possibilities for the output level Q once again becomes less sharply curved, i.e. Q^{LR} . This means that it is possible to move onto the lower isocost, $C_2^S C_2^S$, and substitute out of energy in favour of capital, shifting production round the edge of the isoquant to a new cost-minimising point, Z, with the input mix (K_2, E_2) .

In recognition of this 'putty-clay' issue, some models distinguish between different vintages of capital. For example Burniaux *et al*'s (1992) GREEN model has both 'old' and 'new' capital coexisting in each period as part of its dynamic structure, with the 'old' capital having been installed in previous periods, and the 'new' capital resulting from current-period investment.

The argument that observations of differing substitutability between factors of production can be explained by the non-homogeneity of factors like 'capital', 'labour' and 'energy', and that different types/vintages of capital may substitute against (different types of) energy in different ways, is likely to be a valid one. In the case of labour there have also been suggestions that disaggregating labour into different skill/occupational categories would mean that different substitution possibilities with other factors of production could be captured.

I would argue, therefore, that the only way to deal with the problem of differing substitutability over time due to heterogeneity of inputs is to explicitly model different types of capital, labour and/or energy where it is appropriate to do so. This is not entirely a problem of functional form. Rather it is partly one of what level of detail is incorporated in modelling different factors of production.

Other explanations have been offered as to why the substitutability between capital and energy has been found to differ in different studies. Field & Berndt (1981) suggest an important reason why this may be the case: the lack of standardisation across models regarding the level of sectoral disaggregation. A number of studies have shown that the relationship between capital and energy tends to differ across sectors. This suggests that in modelling sectoral detail, just as in modelling input detail, over-aggregation is likely to have a distorting effect on elasticity estimates if differing elasticities of substitution are hidden within an aggregate effect. This point is reflected in a number of the models reviewed here. For example Bergman (1990) cites a study of factor demand in Sweden⁷, which reported that the cross-price elasticities between capital and energy are low and positive in some sectors, and negative in others, implying that they are substitutes in some sectors and complements in others.

3.3 Dealing With The Problem Of Differing Substitutability Among Inputs

⁷ Walfridsson, B. (1987) 'Dynamic Models of Factor Demand: An Application to Swedish Industry', University of Gothenburg.

Some authors suggest practical ways of dealing with the differing substitutability problem. For instance, Despotakis & Fisher (1988) argue that the lack of consensus on production relationships involving energy means that it is impossible to choose a unique set of elasticities for substitution between energy and other factors, leading them to choose a base set and perform sensitivity analysis. However, referring back to the discussion in Section 3.1, I would highlight the fact that the sensitivity analysis performed by Despotakis & Fisher (1988) extends only the sensitivity of the model to parameter values, and not to alternative production structures/separability assumptions.

Hertel & Mount (1985) attempt limited econometric estimation of substitution parameters. While their model (of New York State) is largely calibrated, they econometrically estimate all elasticity of substitution parameters within their primary factor aggregate, which includes energy, using pooled data from counterpart sectors in comparable US states. Hertel & Mount's (1985) estimation procedure involves estimating the two level FFF production structure described above in Section 3.1: first the translog energy aggregate (E) was estimated, then a KLE aggregate (materials were modelled under the assumption of Leontief technology, due to data restrictions). At each stage the unit cost function and share equations were combined using a maximum likelihood estimation method to give implied derived demand elasticities as linear functions of the share and cost function parameter estimates. Individual estimations were carried out for three different manufacturing industries, since, in addition to the capital-energy problem noted above, the relationship between energy and *labour*, as well as that between different types of energy (electricity and fuels), has also been observed to differ across industries.

The three manufacturing sectors identified by Hertel & Mount (1985), for which individual estimates were carried out were 'primary metals', 'chemicals' and 'other manufacturing'. They find labour and energy to be complementary inputs, with negative cross-price elasticities (of varying magnitude) in all three of the manufacturing sectors modelled. They say that this finding contradicts some US national results, where labour and energy are marginal substitutes, but is consistent

with other results for a sample of states. They also state that the results of dynamic models that have shown that the relationship between labour and energy changes over time, being short-run substitutes but long-run complements in some sectors⁸. (However, in this case (as in general) we should bear in mind the arguments made in Section 3.2 above over the specific nature of the elasticity estimates in different studies.)

Hertel & Mount (1985) explain that their (short-run) results suggest that capital and energy are in fact substitutes in production, in contrast to the arguments I have noted above regarding observed complementarity between capital and energy in the short-run. However they state that this short-run substitutability result is consistent with other studies which break capital down into working and physical capital, rather than the different vintages of the 'putty-clay' argument. (Griffin (1981) also argues for making the distinction between working and physical capital.)

Despite the arguments put forward by Hertel & Mount (1985), Hertel (1988), Li & Rose (1995) and Depotakis & Fisher (1988) in favour of employing a FFF in modelling production, most of the models that I review here employ nested production structures that are a combination of CES, Cobb-Douglas and Leontief relationships. Given what I have argued so far in this chapter, this is most likely for reasons of simplicity and/or, in cases with multiple inputs, of tractability. That is to say, there is likely to be a trade-off between the flexibility offered by imposing as few priors as possible on the production structure, and tractability when it is desirable to incorporate the multiple inputs (and outputs) that characterise actual production decisions in a real economy.

Moreover, note that Hertel & Mount's (1985) econometric estimations do not extend to all parameter values and do not appear to extend to testing the *specification* of their FFF model. This emphasises the point that I have already made above. *None* of

⁸ Hertel & Mount (1985) do not give any published references to allow me to investigate the nature of the estimates that lead to the results they state with respect to the labour-energy relationship. The only study they cite, as an example, is a conference paper – Denny, M., Fuss, M. and Waverman, L. (1979) 'The substitution possibilities for energy: evidence from the US and Canadian Manufacturing Industries' (presented at the NSF on Natural Resource Substitution, Key Biscayne, Florida).

the decisions regarding appropriate functional form in any of the models reviewed here appear to be based on formal testing of model specification, which would seem to be the most appropriate basis upon which to argue for one functional form or another. Undoubtedly the common reason for not undertaking full tests of model specification will be that this would be a highly impractical task in the case of most general equilibrium models. However, I would argue that there is a problem in the fact that none of the models reviewed here even *explicitly* discuss this issue. This may obscure the fact that much of the debate in this area appears to be based mainly on each modeller's *judgement* of what is an appropriate functional form in the specific situation at hand.

However, bearing in mind the impracticality of conducting full model specification tests on a complex general equilibrium model, one conclusion that I would draw from all this is that the production structure should be as flexible as possible (without implying that FFFs need to be adopted). Although it is very data-intensive, and therefore not a viable option in many cases, I conclude that case-specific elasticities of substitution should be estimated where possible and sensitivity analysis of elasticity parameter values should be conducted to reflect uncertainty surrounding the values.

Moreover, the observations by Hertel & Mount (1985) and Bergman (1990, 1991) that elasticities between the same pair of inputs vary across sectors, suggests that the flexibility of the production structure should be extended to allow differing elasticity of substitution across sectors. This is the case in a number of the models reviewed here, with some going one step further and specifying different distinct production structures for different industries. For example in Naqvi (1998) there are six different types of energy demand structure, to allow for differing patterns of energy demand, particularly in energy intensive industries.

The popular approach of employing CES-CD-Leontief nested structures *could* also cope with the problem of differing elasticities of substitution between a given pair of inputs over time by exogenously changing these parameter values over different

conceptual time periods. This could be done in applications of static models that include short, medium and long run simulations, defined in terms of the fixed or variable status of different factors (though this is not common practice among the models reviewed here).

In terms of sensitivity analysis, Borges & Goulder (1984) apply a practical idea in their model of the US economy. They address the question of the appropriate flexibility of production technology by specifying alternative production structures in order to test the impact that the degree of flexibility has on their simulation results in terms of the aggregate performance of the economy and on the behaviour of individual sectors. They specify a production sub-model with varying degrees of flexibility in the technical coefficients. A lower bound to the range of potential flexibility in production technologies is provided by a fixed coefficients version of the model, where simple Leontief technology is specified for all intermediate inputs (materials and energy) and value-added, combined with a Cobb-Douglas nest for capital and labour to give gross output. Assuming a production structure with a full set of Cobb-Douglas specifications (i.e. all elasticities of substitution equal to one) provides the upper bound to the range of flexibility in production technology for the simulations. An intermediate case is specified where flexibility is reduced (compared to the upper bound case) for certain key combinations of inputs within a nested structure; in particular with capital and energy being treated as fully complementary. Borges & Goulder (1984) find that the result of varying the flexibility of production technology in this way is considerable variation in the effects (of an energy price change) on both the aggregate performance of their economy, and on individual sectors, particularly in the energy area. While authors of more recent models would perhaps argue that the alternative specifications tested by Borges & Goulder (1984) are too limiting (with no CES nor any FFF cases⁹), this is nonetheless a useful

⁹ However Borges & Goulder (1984) use the argument that to achieve energy-capital complementarity, it is sufficient that the substitution between energy and capital be substantially smaller, even if it is positive, than the elasticity of substitution between the resulting capital-energy aggregate, labour and materials in the outer nest. Since they assume that this elasticity in the outer nest is equal to one (assuming a CD relationship), this implies an elasticity between zero and one which would imply a CES relationship (unless a Leontief relationship is assumed for perfect complementarity), although this is not explicitly stated.

approach to the question of how important flexibility in the production structure is in different modelling applications.

Conrad (1999) suggests a similar type of approach. By assuming a CES specification first with a low elasticity and then with a high elasticity, he argues that it will be possible to get “an interval for the economic consequences of regulation” (p.1067) that may be more informative than getting a precise econometric estimates of the elasticities of substitution. Bearing in mind the observations of capital-energy complementarity, however, I would argue that it is important to ensure that this interval captures the full range of possibilities. Note, however, that if CES is used to approximate a CD relationship it becomes numerically unstable. Therefore it is more appropriate to employ the full range of Leontief, CES and CD relationships.

In terms of the separability assumptions that are necessary if different substitution possibilities across different pairs of inputs are to be captured in a CES/CD/Leontief production structure, it would also, in principle, be possible to specify a range of alternatives to test the sensitivity of different separability assumptions. However this would essentially mean stating a different version of the production side of the model for each alternative, which may not be a practical option.

Li & Rose (1995) make an important general point: that pre-investigation of substitution possibilities in the economy in question should be carried out since case-specific differences are very important. This is the point that I have raised above, in the introduction to this section, regarding the importance of the institutional setting and actual economic conditions in the economy in question. Li & Rose (1995) make the point with respect to the choice between different types of FFF. Nevertheless, it is one which will apply generally, for example in the decision over what factors of production to incorporate, as we will see below (where I examine different choices of CES nested production structures).

However, my observation is that this crucial point regarding the need for pre-investigation of the specific case being modelled *and* the need for sensitivity analysis

is not clearly made in any of the articles discussed here. If there are a variety of possibilities regarding, for example, what variables to include, and how to include them, what is really required is some type of general-to-specific testing. In other words, strictly speaking what should be done is testing of all possible combinations of variables, functional forms etc. The argument that a flexible functional form must be better than a CES/CD/Leontief structure when modelling energy has limited relevance unless one tests the extent to which this is the case. The benefits gained from econometric estimation using historical case-specific data will be greatly reduced if the model specification is incorrect, and this can only be determined by tests of model specification against a full range of alternatives.

Of course, as I have already stated above, in practice testing a full range of alternatives and controlling for all influences in each possible specification in a general equilibrium setting would be a very difficult and, in most cases, a highly impractical task. However, the point I wish to emphasise is that none of the models reviewed here explicitly acknowledge that their choices of model specification are, at the end of the day, based on the modeller's best judgement rather than some objective process to determine the best alternative. There is of course *implicit* acknowledgement of this point with the inclusion of sensitivity analyses. However, I would argue that it should also be made clear that these sensitivity analyses are confined within certain boundaries that are again determined by the modeller's best judgement. My point is that while there is no easy solution to the problem of the difficulty of general-to-specific testing in a general equilibrium setting, it would seem important that modellers be explicit as to whether modelling decisions have been based on judgement, testing or a combination of both. This would seem more informative than attempting to argue that one judgement must be better than another, and would leave the way open for future testing of alternative specifications when and if time and resources permit.

4. Survey Of Approaches To Modelling Production With Energy Inputs

In Section 3 I have discussed some key issues involved in modelling production where energy is a main input. In this section I look at how production decisions involving energy as a key input have actually been modelled in existing economic-environmental CGE models. Generally it can be said that the models reviewed here distinguish between at least two levels of substitution: (1) between energy and other factors of production, and (2) between different energy types. I survey the range of approaches to modelling these relationships in Sections 4.1 and 4.2 respectively. Another general observation is that, as I have noted above, most of the models reviewed here employ nested production structures involving a combination of CES/CD and Leontief relationship. However, in terms of the separability assumptions involved, there is significant variation among these models.

4.1 Substitution Between Energy (Aggregate) And Other Factors Of Production

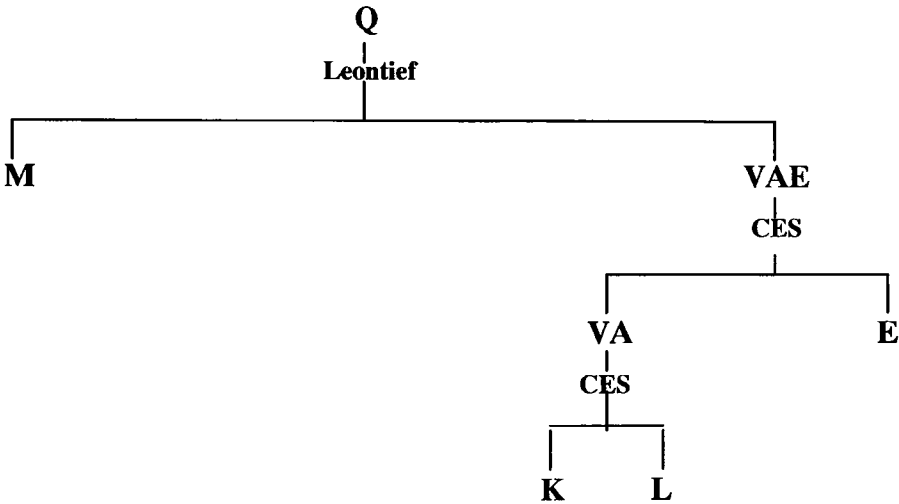
The models that I review here demonstrate alternative ways of dealing with substitution between energy (E) and the other factors of production (mainly capital (K), labour (L), and intermediate materials (M) – known as KLEM production functions). The four FFF models - Hertel & Mount (1985), Hertel (1988), Li & Rose (1995) and Depotakis & Fisher (1988) - are the only ones that can allow different pair-wise substitutions among all the individual aggregates of capital, labour, energy and intermediate materials. These substitution possibilities are modelled on the top level of their GL or translog cost functions (with inter-energy substitutions on the bottom level).

The rest of the models that I review here use nested CES-CD-Leontief production structures, which means that they employ separability assumptions among the KLEM inputs. Generally energy inputs (making up the energy composite, E) are produced by the energy sectors of the economy in question or imported, but are treated in a different manner to the non-energy (produced) intermediates. In most of the models, energy inputs are combined in some way with the primary factors which make up value-added (VA) to form a value-added/energy (VAE) composite which then combines with an aggregate of intermediate inputs (M) to produce gross output (Q).

In most cases the primary factors are capital (K) and labour (L), but some of the models include land and/or other sector-specific natural resources (both of which are referred to as NR below) within the category of value-added.

The first important issue is how the VAE composite is formed; i.e. how separability assumptions are applied in combining value-added and energy. One of the main criticisms of using nested CES type production structures is that where there is only substitution between pairs of inputs, and one of the inputs in a pair is itself an aggregate of two inputs, then both of these inputs must substitute equally well for the third. Among the models I review here, there are several different approaches to forming the VAE composite. In combining energy with the value-added composite, the most straightforward approach may appear to be that taken by Stephan *et al* (1992), Böhringer & Rutherford (1997) and Zhang (1998). This approach is illustrated as VAE Case A in Figure 4.3, where VAE is a CES combination of the VA (labour and capital) composite and an energy composite.

Figure 4.3 – VAE Case A: CES Combination Of A K-L Aggregate And Energy



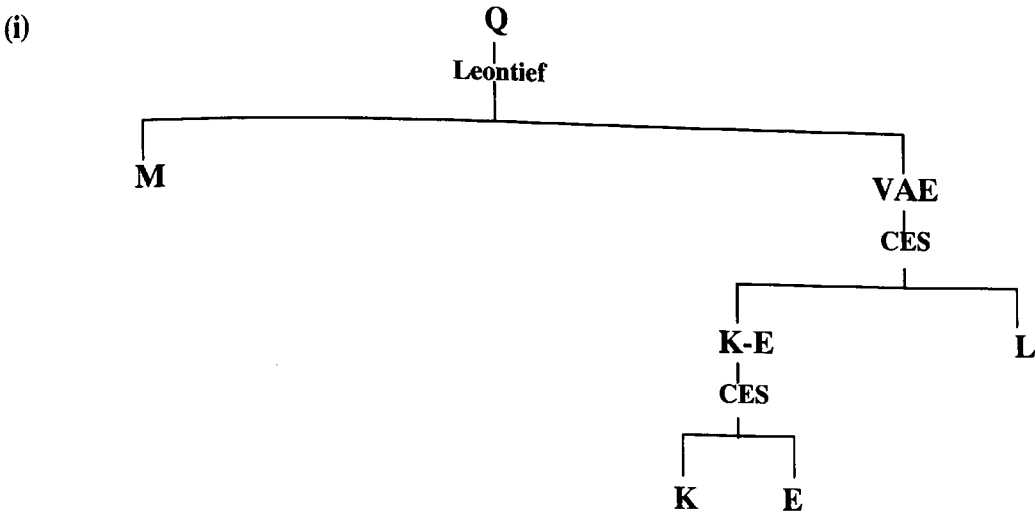
VAE Case A: Stephan *et al* (1992), Böhringer & Rutherford (1997) and Zhang (1998)

However the separability imposed by the nested production structure employed in these three models (Figure 4.3) implies that both capital and labour substitute equally well for energy. This may or may not be a reasonable assumption in the specific cases of the target economies being modelled (Switzerland, West Germany and China respectively), but a general observation is that while energy and labour are normally substitutes, this may not always be the case for energy and capital. It is perhaps because of the energy-capital controversy discussed above that the most common approach in the models reviewed here is combining a capital-energy aggregate with labour to produce the VAE composite. In other words, the most popular approach in the models reviewed here is to make the assumption that both capital and energy substitute equally well for labour (which is a reasonable assumption according to some results), keeping the controversial substitution between capital and energy separate. For example this approach is adopted by Beghin *et al* (1995) and Kamat *et al* (1999)¹⁰, and illustrated in Figure 4.4 as VAE Case B(i). Bergman (1990, 1991) and Burniaux *et al* (1992) adopt a similar approach, but replace the K-E aggregate with a K-E-NR aggregate, to incorporate sector-specific natural resources – see VAE Case B(ii) in Figure 4.4.

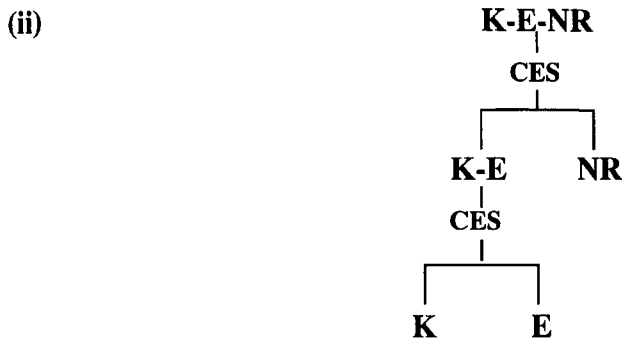
In Figure 4.4 I also illustrate the approach of Borges & Goulder (1984) as VAE Case B(iii). This model also opts for a capital-energy aggregate, but instead of output being specified as a Leontief combination of a VAE aggregate and intermediate materials, M, it is a CD combination of materials, labour and the capital-energy aggregate. The capital-energy aggregate is modelled where capital-energy complementarity is assumed (which Borges & Goulder (1984) say they believe to be the correct assumption). Where this is the case, capital and energy are modelled using a Leontief relationship in a second-level nest. Where capital-energy substitutability is assumed the production structure collapses to a single level CD relationship between the KLEM inputs.

¹⁰ It is interesting to see the use of nested CES functions in Kamat *et al* (1999) because one of the authors here, Adam Rose, was also co-author of the earlier Li & Rose (1995) paper on the Pennsylvania model. In that paper the argument was quite strongly made for using a FFF because of the limitations of CES when energy is involved.

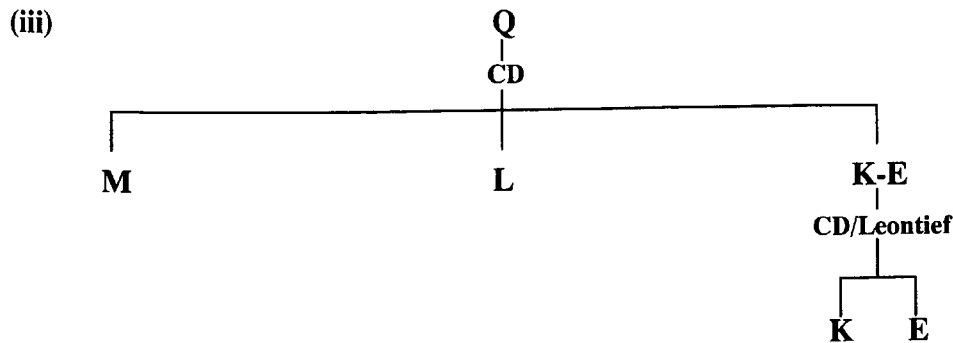
Figure 4.4 – VAE Case B: CES Combination Of A K-E Aggregate And Labour



VAE Case B(i): Beghin *et al* (1995) and Kamat *et al* (1999)



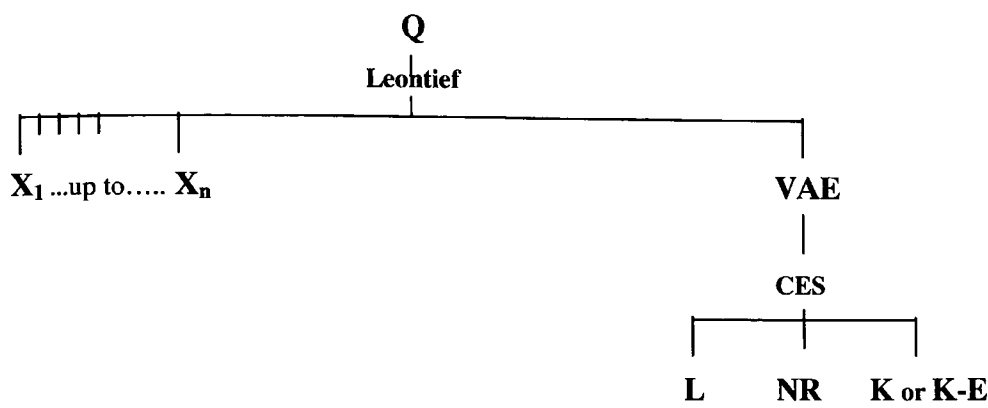
VAE Case B(ii): Bergman (1990, 1991) and Burniaux *et al* (1992)



VAE Case B(iii): Borges & Goulder (1984)

One other model, Naqvi (1998), adopts the approach of combining intermediate energy inputs with value-added inputs (capital, labour and land) in some sectors. This model has the most detailed modelling of energy supply and demand of all those I review here, with energy entering the production structure in several, sector-specific ways. Figure 4.5 is a generalised illustration of the production structure assumed by Naqvi (1998).

Figure 4.5 – VAE Case C (Naqvi, 1998)



X_1 to X_n are the intermediate inputs in Naqvi’s (1998) model, both energy and non-energy commodities, which combine with the value added composite to produce output. In some sectors a number of the intermediate energy inputs enter as part of a capital-energy composite, replacing capital in the basic structure, reflecting different supply and demand patterns for energy in different sectors of the Pakistan economy (particularly the energy supply sectors, agriculture, manufacturing, construction and transport sectors).

Note that this model allows a three-way CES substitution between primary inputs to produce a primary factor aggregate, which is generally made up of capital, labour and land, but with some energy inputs entering as part of a capital-energy/fuel aggregate in the place of capital in specific sectors. However this carries the implication that the elasticity of substitution between all factors in the VAE composite must be the same which would appear to be inconsistent with many

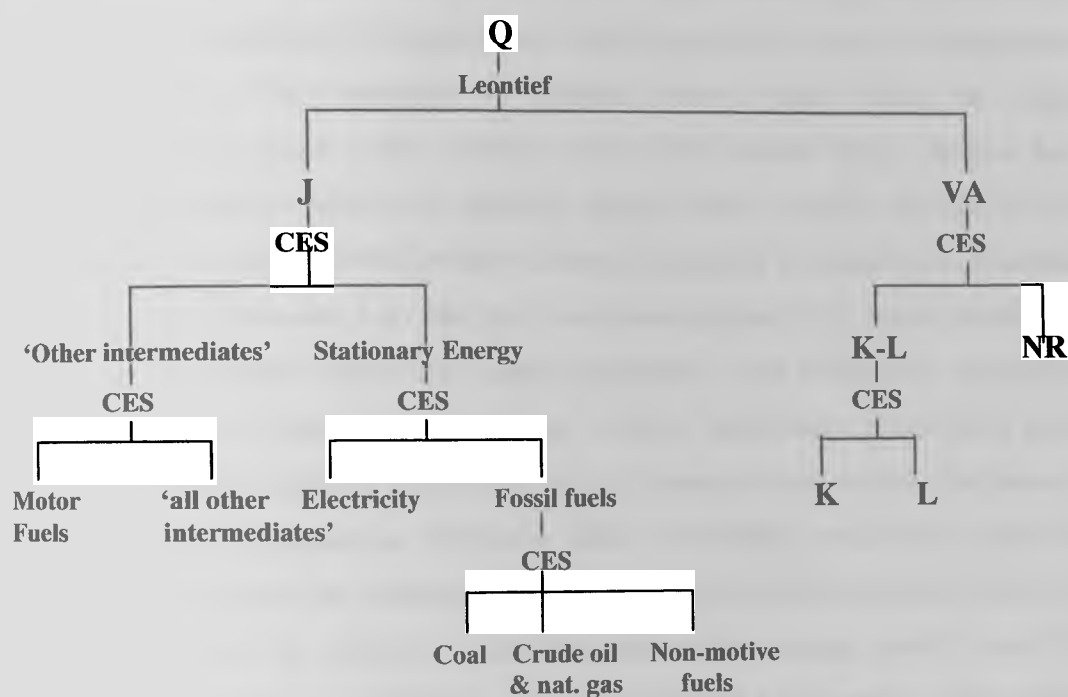
results, particularly where energy is involved. Moreover, even if energy is *not* included in this aggregate, Boyd & Uri (1991) argue that a direct combination of land, labour and capital is unsuitable because it means implicitly assuming that the elasticities between all pairwise combinations of the three are the same. Instead, Boyd & Uri (1991) choose to model capital as a capital-land aggregate that then combines with labour.

It is not clear why Naqvi (1998) chooses this three-way CES substitution between the primary inputs, instead of using a separability assumption to allow substitutions between land, labour and capital to differ. Nor is it clear why the individual intermediate inputs are combined with VAE at the top level, instead of combining VAE and an intermediates aggregate. Indeed these decisions seem all the more peculiar if we bear in mind the fact, as I pointed out above in Section 3.1, that Naqvi (1998) is the article which argues in favour of using separability assumptions to keep a multi-input and multi-output production specification “manageable” (p355). It seems odd then not to employ separability assumptions at such crucial parts of the production specification.

Another model with a very detailed treatment of energy is Beauséjour *et al* (1994, 1995). However this model does not distinguish separate intermediate aggregates for materials and energy. Instead a ‘stationary energy’ aggregate combines with ‘other intermediates’, the latter including one energy type, motor fuels, to form an intermediates aggregate (referred to in Figure 4.6, below, as J). The VAE approach of the other models discussed above is not adopted here: with energy being dealt with as part of the intermediates aggregate, it is treated as separable from capital, labour and other natural resources. Seven natural resources are modelled as part of VA are sector-specific resources, entering (in fixed supply) as part of value-added in the case of the six resources industries modelled – agriculture, fishing, forestry, non-coal mining, coal mining, crude oil and natural gas – and the electric utilities industry. No explicit rationale is given by Beauséjour *et al* (1994, 1995) regarding why energy is not combined with VA, with capital in particular, at an earlier stage than the combination of intermediates and VA to produce gross output, as it is in

most of the other energy-economy models examined here. However, Beauséjour *et al*'s (1995) decision to model their production structure in this way implies that they do not consider the issue of capital-energy substitutability to be of special importance. They choose instead to focus on the nature and substitutability of individual energy types with respect to other energy types and intermediate goods, assuming, by the separability assumptions imposed, that all energy and non-energy intermediate goods are related to all components of value-added only through a fixed proportions Leontief relationship.

Figure 4.6 – Treatment Of Energy In Beauséjour *et al* (1994, 1995)



As I have already argued in Section 3, there is no way of saying which of these approaches to modelling production structure is ‘right’ as there does not appear to be any testing of model specification in any of the cases reviewed here. Moreover, what is appropriate for one economy may not be appropriate for another; I have already discussed how the economy-specific context will be important in determining the model structure and specification. Another factor that will influence the approach taken (one that is likely to be important in the case of the model being built for the current project) is that the actual structure of the economy as described by the base

year dataset may limit the possibilities for model specification. In particular, if interaction between (identified) sectors in the local economy is limited to such an extent that the materials and/or energy intermediates matrix is characterised by a lot of zeros, this may actually rule out multiplicative functional forms such as CES at certain points in the production structure.

4.2 Detail Of Energy Modelling And Possibilities For Inter-Energy Substitution

4.2.1 Different Types Of Energy Modelled

My literature review shows that the detail of energy modelling, and possibility of inter-energy substitution is regarded as another important issue in environmental CGE modelling. The treatment of different energy types within the energy aggregates varies quite widely across most of the models that I review here. Therefore I make no attempt to illustrate general cases: only the specific case of Beauséjour *et al* (1994, 1995), where no energy aggregate is modelled, is illustrated (in Figure 4.6). However, I do find that a common approach is to model nested CES production structures within the energy aggregate, with multi-level substitution between different types of energy inputs to allow substitution possibilities based mainly on carbon content. I identify this as key feature of most models that focus on energy inputs to production. However, while substitution possibilities based on carbon content reflect the common focus of most of these studies on the emission of greenhouse gases, the choice of modelling intermediate energy goods using CES technology is a more general feature of energy-economy CGE models. The common assumption of Leontief technology for intermediate input demand is generally considered to be inappropriate for intermediate energy inputs. This assumption is therefore generally relaxed in energy-economy models by introducing CES technology within energy input aggregates in order to allow for inter-fuel substitution.

I find that the other key factor determining inter-fuel substitution possibilities is the number of different types of energy inputs modelled. Lack of detail in modelling

energy is regarded by Dean & Hoeller (1992) as a major limitation of models like the Whalley-Wigle model (as described in Whalley & Wigle (1992)), which only differentiates between carbon and non-carbon based energy. Dean & Hoeller (1992) argue that in other models, which identify different types of carbon-based energy, the possibility for inter-fossil fuel substitution is regarded as an important factor in reducing CO₂ emissions since different fossil fuels have different carbon intensities. However it is not only in modelling CO₂ emissions that inter-energy substitution is important, and the models reviewed here illustrate a variety of substitution possibilities. As an illustrative example, Li & Rose (1995) demonstrate the wide range of general equilibrium effects that can be captured with detailed energy modelling. In response to a carbon tax their simulations produce (a) inter-fuel substitution among fossil fuels, favouring natural gas (reflecting carbon intensity); (b) inter-fuel substitution with fossil fuels displaced by non-fossil fuels such as nuclear power (reflecting carbon content). In addition to these substitution effects within the energy aggregate, Li and Rose (1995) find that in response to carbon taxes there is further substitution away from energy toward the other factors of production, in a move away from fossil-fuel/energy intensive production technologies. They also find some redeployment of capital and labour out of energy-intensive industries (which in this case, since the region being modelled is heavily industrialised, means some migration of these factors to other regions)¹¹.

The most commonly identified energy types in the models I review here are oil, gas, coal (the three basic fossil fuel types) and electricity - e.g. Depotakis & Fisher (1988), Burniaux *et al* (1992) (GREEN model), Stephan *et al* (1992), Li & Rose (1995), Böhringer & Rutherford (1997) and Zhang (1998). However, some of the models identify more, most often as sub-categories of the four basic energy types listed above, to reflect different forms and uses of the basic energy types. For

¹¹ However, one point I should make with regard to Li & Rose's (1995) model concerns the nature of the shock – a world-wide, and therefore nation-wide, carbon tax - and their decision to model the Pennsylvania economy as a single region. Their argument for regional modelling is a solid one: that different regions are likely to be differently affected by a carbon tax because of differing economic structures. However, since the tax is not region-specific, instead affecting *all* US regions, I would argue that it would be more appropriate to build an inter-regional model of the national economy or at least a model where the rest of the US is endogenous. Since the tax is a nation-wide one, if the rest of

example, it is possible to break oil down into combustibles, gasoline and non-energetic inputs, because oil can be used directly in non-combustion processes which do not lead to CO₂ pollution. Electricity can also be generated without causing CO₂ pollution by nuclear and/or hydropower stations, and some of the models identify such processes (for example Li & Rose (1995) identify nuclear power). Other types of energy are also identified in some cases: for example, Böhringer & Rutherford (1997) model steam and warm water. Beauséjour *et al* (1994, 1995) has very detailed energy modelling with electricity, four fossil fuels and separate 'motive fuels' modelled as intermediate inputs, as well as the six sector-specific natural resources that are modelled as primary inputs (in fixed supply). (As I note above, these resources are only identified by the 'resource industry' that uses them in production, but it is not clear exactly what resource is used, for example, in the case of agriculture or fishing). Some others, as in Whalley & Wigle (1992), identify less than the basic four: e.g. Hertel & Mount (1985) with only electricity and purchased fuels. Bergman (1990, 1991) only identifies energy and imported fuels, but also models a sector specific natural resource (roundwood, used in the 'Forest' industry, which is an aggregate of the forestry and pulp and paper industries).

However, as explained by Naqvi (1998), the decision over what energy/natural resource types are modelled is largely dependent on the actual nature of energy/resource demand and supply in the economy in question. For example, Naqvi (1998) does not model consumption patterns for coal in any detail, since coal only meets a small fraction of energy demand in the Pakistan economy. Moreover, coal consumption is concentrated in one sector of the Pakistan economy (the bricks industry), where existing production technology renders substitution of coal with any other commercial energy product impossible. This all implies that the country-specific setting of the model in question will be a crucial factor in terms of the detail of energy modelling and the energy types modelled.

The different types of energy identified would also seem to reflect the problem that the modeller is attempting to examine with respect to pollution (I discuss exactly

the US is modelled as exogenous, and therefore unaffected by its imposition, the effect on the region

how emissions are modelled in Section 5). Models that focus mainly on CO₂ emissions, and particularly policies to affect these using carbon taxes, appear to pay most attention to the relative carbon content of different types of fossil fuels. This is because CO₂ emissions are primarily dependent on the fuel properties, with generation resulting from any economic activity relating directly to the amount and carbon content of fuel combusted (Coley, 1994). However, where models focus on a wider range of pollutants, the generation of emissions from fuel use depends on a many more factors than carbon content. This is perhaps why Beauséjour *et al* (1994, 1995) emphasise the distinction between ‘motive’ and ‘non-motive’ fuels: the generation of non-CO₂ greenhouse gases like methane (CH₄) and nitrogen dioxide (N₂O) depend heavily on combustion conditions and technology as well as on fuel types. For this reason the Intergovernmental Panel on Climate Change (IPCC) recommend that non-CO₂ emissions are treated separately from CO₂ emissions, with the main factor determining the level of emissions generated during economic activity being whether fuel use and combustion take place in a stationary or non-stationary source (Coley, 1994).

4.2.2 Possibilities For Substitution Between Domestic And External Sources Of Supply For Energy Inputs

Prior to the possibilities for substitution between different *types* of energy, most of the models reviewed here first model the choice between domestic and imported sources for each energy type considered (and this is true in terms of consumption as well as production decisions). As is the case in CGE models in general, the ‘Armington Assumption’ is often employed for tradable commodities, in circumstances where foreign and domestically produced goods are imperfect substitutes for one another, allowing domestic (endogenous) and world (exogenous) prices to differ¹². In the models that I review here, this is generally achieved by using a CES functional form to model the demand for imported and domestic inputs to production (or consumption goods). The decision over whether production outputs

being focussed on is likely to be dramatically exaggerated.

are destined for domestic or export markets is generally modelled using constant elasticity of transformation (CET) functions, in the same manner as multiple outputs by any sector. The CET function specifies the degree of transformation of outputs that is possible between goods destined for domestic and export markets/between alternative outputs, just as the CES function specifies the degree of substitution between alternative inputs that are imperfect substitutes.

In some models there is no choice between imported and domestic energy inputs: for example, in Stephan *et al*'s (1992) model of the Swiss economy, there is no domestic production of fossil fuels or any other carbon-based energy commodity, meaning that all carbon-based energy inputs are imported. However in several of the models I review here, where there is a choice – for example, Borges & Goulder (1984), Goulder (1995), Beaséjour *et al* (1994, 1995) and Böhringer & Rutherford (1997) – the Armington assumption is dropped in the case of some or all energy inputs. Borges & Goulder (1984) and Goulder (1995) explain that all domestic prices are endogenous in their models, except the domestic prices of oil and gas, which take the exogenous world price. This means that foreign and domestic supplies of oil and gas are treated as perfect substitutes, with perfectly elastic supply at given world prices. In Böhringer & Rutherford (1997), domestic and foreign supplies are regarded as perfect substitutes in the case of *all* energy goods. Beaséjour *et al* (1994, 1995) also drop the Armington assumption in the case of several industries – the fishing, forestry, non-coal mining, and petroleum product industries – where they say they adopt the Heckscher-Ohlin assumption of homogeneous products.

I conclude that the specific context of the model in question is again important here. The decision over whether to model domestic and imported natural resource and energy supplies as homogenous products or imperfect substitutes is likely to be a case-specific one (i.e. what is best suited to the economy being modelled). However, I would argue that the key question is whether domestic and foreign produced factors, such as “oil” and “gas”, *are* in fact effectively homogeneous. If this is the

¹² Note that, in principle, an Armington function can be used to capture anything from a Leontief ($\sigma=0$) relationship between locally and externally produced commodities to the homogeneous goods/Law of One Price case ($\sigma=\infty$).

case, then the domestic economy will be a 'price-taker' in markets for these factors, and the Heckscher-Ohlin assumption will be a reasonable one. On the other hand, Peng & Martin (1994), in a model of China, say that they employ the Armington assumption for all traded goods, including the particular example of petroleum products, precisely for the purpose of allowing the domestic and world prices to differ. The question, then, is whether it is reasonable to assume that Chinese and ROW petroleum products are genuinely distinct goods, or whether domestic and foreign prices differ for some other reason¹³.

5. Issues Involved In Modelling Pollution Generation

Modelling pollution generation is a more recent innovation in CGE modelling than modelling energy use and not all the models that I review here incorporate this element. Even though waste and pollution generation are generally associated with energy use in an economy, a number of the energy-economy CGE models reviewed here appear to have been built solely for the purpose of analysing the *economic* effects of energy-use issues, such as changes in energy prices and taxes. Bergman (1988) explains that interest in energy-economy modelling arose in the 1970s and 1980s in response to public concern about the economic impact of changing energy supply conditions. This is an important research area in itself, and the focus of these models does not extend to how these effects feed through to the environment, or more generally the environmental effects of economic activity.

However, as international concerns grow over the problem of global climate change, and people become more concerned over local environmental quality, CGE modelling efforts have increasingly begun to focus on the problem of pollution generated during economic activity. Most of the models I review here focus on the generation of greenhouse gases, and the economic and welfare effects of environmental policies employed to combat this problem, rather than on the question of local environmental quality. I discuss this point in Section 5.1. Another general

¹³ Peng & Martin (1994) explain their use of the Armington assumption by explaining that world and domestic prices differ because of a 'two-tier' (official and market prices) price system in China. However it is questionable as to whether the Armington assumption is the best way to deal with this.

point I identify from my literature review is that, as in modelling energy use, the specific context for which the model is being built is important. That is to say, the nature of pollution problems differs across economies with different production and consumption patterns, as do the objectives of policymakers.

As well as focussing on the generation of pollutants, CGE modellers have given attention to what was one of the earliest innovations in (theoretical) economic-environmental modelling: incorporation of pollution abatement technologies into the general equilibrium system. This is discussed in Section 5.3.

However the key issue for modelling the relationship between economic activity and the environment has been whether this relationship should be modelled as one between the generation of pollution and (a) inputs to production, and/or (b) the outputs of domestic sectors and imports which are consumed within the economy. I look at how this question has been addressed in the literature in Section 5.2.

5.1 Which Pollutants Are Modelled

I find that the main factor determining the choice of individual pollutants to be incorporated is the purpose that the model has been set up for. For example, as I point out above (in Section 2), the focus of global models like GREEN tends to be on global sustainability questions like the emissions of greenhouse gases, in particular CO₂ (which is the biggest contributor to the global warming effect). Therefore Burniaux *et al* (1992) (GREEN) only models this single pollutant (the focus of this application of GREEN is to quantify the costs of curbing CO₂ emissions), while Barns *et al* (1992) (a partial equilibrium model) model more than one greenhouse gas, namely CO₂, CH₄ and N₂O. Modelling of multiple pollutants seems to be more common in the case of individual region/country or sub-global inter-regional/inter-country models, most likely reflecting the different type of environmental concerns which exist at local (national/regional) levels. For example, Beghin *et al* (1995), a single country model of Mexico, models thirteen water, air and soil pollutants, and

Lee & Roland-Holst (1997), a two-country CGE model of Indonesia and Japan, models eleven air, water and toxic pollutants.

Moreover, it appears that the question of how wide a variety of pollutants are modelled depends on whether the model has been built to address a specific policy concern that exists in the target economy. I argue above (in Section 2) that non-global (or local) models will often focus on greenhouse gas emissions in terms of the constraints that international or voluntary commitments to limit emissions impose on economic activity. This is the case in several of the models reviewed here. For example, Bergman (1990, 1991) only models greenhouse gases, a decision motivated by the fact that Sweden's self-imposed limits on greenhouse gases, along with a ban on nuclear power stations, are commonly regarded as significant constraints on Swedish economic activities. Böhringer & Rutherford (1997), in a single-country model of the West German economy, only model CO₂ emissions because the focus of their model is to analyse the effects of carbon taxation schemes that include exemptions for energy- and export-intensive industries. Similarly in their model of Switzerland, Stephan *et al* (1992) only model CO₂ because of policy interest in the effects of stabilising emissions of this, the most important greenhouse gas. Conrad & Schröder (1991a, 1993), in a model of a German region (state), model the greenhouse gases CO₂, SO_x, NO_x (as well as particulates) in order to examine the impacts of a range of environmental policy options.

5.2 Whether Pollution Is Related To Inputs Or Outputs

The simplest way to model pollution as a result of economic activity is through linear output-pollution coefficients, representing the amount of pollution per unit of output for each of the different sectors modelled. In Chapter 3 I explain that this approach was one of the earliest steps in environmental IO modelling (Leontief, 1970). However it is still common in both IO and more general CGE modelling thirty years on.

For example in Lee & Roland-Holst's (1997) model, each sector has pollution coefficients that are linear in output for seven air, two water, and two toxic pollutants. This means that pollution is proportionately related to sectoral outputs only. However the authors point out that a major limitation of this approach is that there is no scope for technical substitution *within* sectors, meaning that emissions are proportional to sectoral output regardless of relative prices and factors such as differential pollution taxes. Roland-Holst addresses this limitation in other work: in a co-authored paper, Beghin *et al* (1995), the point is made that if pollution coefficients are output-based and/or only pure Leontief technology is modelled, then the only way to reduce emissions within any sector is to reduce that sector's output. Beghin *et al* (1995) go on to identify three underlying components of changes in emissions levels over time:

- (1) *Composition* – change in pollution induced by a change in the commodity composition of aggregate production (more or less dirty/clean goods)
- (2) *Technology* – evolving cleaner technologies (which usually result in a change in the input mix)
- (3) *Scale* – increase/decrease in pollution attributable to an increase in aggregate economic activity

Where modelling of pollution involves simply relating emissions of pollution to sectoral outputs, only the composition and scale effects will be captured. The easiest way of modelling the technology effect will involve linking pollution emissions to production techniques through input-based pollution coefficients. However, I would argue that it is more useful to split Beghin *et al*'s (1995) 'Technology' effect into two parts:

- (a) *Technology* – evolving cleaner technologies, independent of the input mix (e.g. installing catalytic converters in cars – this would mean a change in the emissions factor applied to the combustion of petrol in cars).
- (b) *Input substitution* - changing the input mix towards cleaner types of energy/fuel (e.g. changing from regular to low sulphur petrol) or towards

non-energy inputs (e.g. reducing the amount of energy used per unit of existing capital).

Of course, there may be instances where both (a) and (b) would occur together – for example, in switching from oil to gas powered heating systems. However, my argument is that it is useful to make the distinction because the manner in which (a) and (b) are captured in a CGE modelling framework differs. Input substitution, i.e. factor (b), will be captured endogenously in a production structure with fixed input-pollution coefficients and appropriate possibilities for input substitutions (e.g. of the type illustrated in the figures in Sections 4.1 and 4.2). Such input substitutions would typically occur in response to a change in relative prices. However changes in technology (i.e. case (a) above) are likely to involve adjustment of relevant input-pollution coefficients and/or changes to the production structure to reflect differing technical relationships in sectors and/or particular input mixes where adjustments have occurred.

One example of linking emissions of pollutants to input use is Beghin *et al* (1995). The approach adopted in this model involves drawing on work reported in Dessus *et al* (1994) on econometrically estimating the relationship between the production of each type of pollution and the level of intermediate consumption of each type of input. However all this work seems to involve is using a basic estimation model in which the emissions of each pollutant are simply regressed on each of the intermediate material inputs used (including fuels and industrial chemicals), with no apparent investigation of causality.

Several of the other models reviewed here also adopt the approach of linking pollution output to the use of energy inputs. However, in contrast to Beghin *et al* (1995), this tends to be done by using information on *emissions factors* associated with different types of fuel use that have been calculated elsewhere. That is to say, pollution coefficients tend to be based on actual technical relationships, rather than econometrically estimated ones. As I note above, in Section 4.2, the application of emissions factors would appear to be the most straightforward in the case of CO₂

emissions, as these are primarily dependent on the fuel properties rather than combustion conditions and/or technology. Most of the models reviewed here that adopt an input-pollution approach focus solely or primarily on CO₂ emissions. For example, Burniaux *et al* (1992) (GREEN), Barns *et al* (1992), Stephan *et al* (1992) and Böhringer & Rutherford (1997) all use CO₂ emissions coefficients based on carbon content for the different fuel types modelled to model input-pollution relationships.

However, modelling input-pollution relationships becomes more complex when it comes to non-CO₂ emissions. This is because non-CO₂ emissions tend to be dependent not only on fuel type, but also combustion conditions and technology, meaning that appropriate emissions factors are likely to be more difficult to identify and numerous for models with a high level of sectoral detail. This may be why Beaséjour *et al* (1994, 1995) introduce the distinction between ‘motive’ and ‘non-motive’ fuels in their production structure, given that IPCC regard the distinction between stationary and non-stationary sources to be the key distinction in measuring emissions generated during any given activity (Coley, 1994). (This issue is discussed in more detail in Chapter 6, when I identify emissions factors and pollution coefficients for the illustrative case of Jersey.)

Not all the models that I review here adopt the input-pollution approach. Conrad & Schröder (1991a, 1993), whose modelling of pollution simply involves using output-pollution coefficients for each sector, claim that in their model, besides using abatement technology, polluting firms *can* react to standards/emissions taxes by input substitution. However, it appears that this is simply because energy inputs in this model are the outputs of the nine energy sectors in the economy. It would seem, then, that Conrad & Schröder’s (1991a, 1993) argument is that the output-pollution coefficients for each energy sector can therefore be regarded act as input-pollution coefficients for the other sectors that use these inputs. However, I argue that this approach is somewhat questionable: the output-pollution coefficients for each energy sector tell us how much pollution is generated in the production of the energy output, not how much pollution will be generated from *using* that energy output as an input

in another activity. In other words, what is being modelled is the pollution *attributable* to each sector, j , by its input choice as a result of pollution generated in the supply of an energy good by sector i to meet j 's demand, *not* the pollution effects of sector j 's use of that input in production. For example, suppose sector j is the transport sector, and firms in that sector buy petrol from sector i , the petroleum refining or oil sector. Under Conrad & Schröder's (1991a, 1993) approach of using sector i 's output pollution coefficients as sector j 's input pollution coefficients, the pollution that will be modelled is that generated in producing the petrol product. My understanding is that what will not be captured are the emissions from the fuel being combusted by lorries etc as part of the transport sector's activities. I should note, however, that this model does overcome one of Beghin *et al*'s (1995) problems with the basic output-pollution modelling originated in input-output modelling: that of assuming pure Leontief technology. By using CES specifications within the energy and non-energy aggregates that make up the intermediate goods aggregate, Conrad & Schröder (1991a, 1993) are able to capture price-induced technical substitution effects in response to policy-induced changes in relative prices. My argument is that it is the pollution effects of such substitutions that cannot properly be captured without input-pollution coefficients that reflect the effect of actually using (combusting) energy products.

The models that I identify above are all concerned with modelling input substitutions through representation of the relationship between input choices and the resulting outputs of pollution. However Beauséjour *et al* (1994, 1995) argue that there is a role for modelling both input-pollution relationships, *and* output-pollution relationships. (This is an argument that Gale (1995) also puts forward in an IO context – see Chapter 3, Section 5.3.) Beauséjour *et al*'s (1994, 1995) model uses output-pollution coefficients to deal with production processes that are inherently polluting, for reasons other than the combustion of fossil fuels, and where the only way to reduce pollution may be to reduce output. Therefore in this model emissions of (air) pollutants in the model arise from (1) the combustion of fossil fuels in intermediate production *and* final demand, and (2) from some industrial processes that are

inherently polluting (such as pulp and paper production) without actually burning fossil fuels.

1. In the case of burning fossil fuels, the model assumes that emissions are a linear function of the volume of fuel combustion.
2. In the case of polluting industrial processes, where emissions are not caused by burning fossil fuels, emissions are assumed to be a linear function of the level of output from polluting industrial processes. (The sectoral disaggregation used by Beauséjour *et al* (1994, 1995) separately identifies the most polluting industrial processes - e.g. 'pulp & paper', which generates CO₂ pollution, and non-ferrous smelting, which generates SO_x).

Bergman (1990, 1991) also makes this distinction, modelling emissions from combustion as proportional to fuel use and emissions from polluting industrial processes as proportional to output. This means that in the models of Beauséjour *et al* (1994, 1995) and Bergman (1990, 1991), industries can reduce emissions by:

- (i) Altering use of inputs – substitution towards 'cleaner fuels' and/or reducing the overall energy-intensity of production
- (ii) Reducing output levels – this is the only option where processes are inherently polluting (i.e. where emissions are not the direct result of input choice)
- (iii) Using emissions abatement technologies if they exist and are economically feasible. This will reduce emissions from any given input-output combination. (I discuss the issue of modelling pollution abatement technologies in Section 5.3 below.)

However, since sectoral output-pollution coefficients are often derived from fuel use data, I would argue that in the case (ii) of inherently polluting processes it would still be reasonable to use input-pollution coefficients but set the substitutability between inputs to zero. In other words, if by 'inherently polluting' production processes we

mean that there is only one way to produce output and the input mix will not affect the generation of pollution, fixing input decisions by Leontief technology means that the input-pollution coefficients effectively act as output-pollution coefficients. The two would be equivalent in terms of impact. In order to study the potential for reducing pollution in the case of such processes, one possibility would then be to switch between alternative production processes or techniques with differential pollution characteristics for key sectors.

5.3 Modelling Environmental Protection Activities

There are a number of possible strategies for attempting to deal with environmental problems, and, depending on how they are constructed, CGE models can be used to investigate the impacts of alternative courses of action. The methods of environmental CGE modelling that I have considered so far in this chapter involve modelling patterns of energy use and pollution generation in the economy. Therefore one thing that such models can be used to investigate is the (environmental and economic) impact of pollution abatement *policies* aimed at influencing the level and pattern of economic activities that the model suggests lead, directly or indirectly, to unwanted pollution generation. For example a carbon tax will change the prices faced by production or consumption activities that involve the combustion of fossil fuels, depending on carbon content. Therefore, such an instrument would be expected to encourage substitution in favour of fuels with a lower carbon content, and/or activities that require less fuel consumption, thereby affecting the pattern and/or level of energy use in the economy and the level of carbon-based pollution generation.

However another possible strategy for dealing with environmental problems involves not so much affecting the level or pattern of economic activity, but instead *treating* the polluting residuals of production and consumption processes. This is sometimes referred to as ‘end-of-pipe’ treatment and will involve cleaning activities, such as scrubbing gas stacks, and/or introducing more ‘environmentally friendly’ technology, such as installing catalytic converters in cars (Pearson, 1989). Neither of

these examples involves changing the level or pattern of economic activity – the production and use of gas can remain constant, as can the use of cars, but the pollution residuals resulting from both types of activity should be more benign. However in order to investigate the impact of such cleaning or protection activities it will be necessary to model more than just patterns of energy use and pollution generation: separate cleaning/protection activities and/or technologies will have to be incorporated in the model.

In Chapter 3 (Section 4.3.2) I explain how the early Leontief (1970) environmental IO model incorporated environmental protection activities as a separate sector as well as modelling pollution generation. However, I also note that only one of the more recent IO models reviewed in Chapter 3, Schäfer & Stahmer (1989), attempts to model such pollution abatement activities in a standard IO model. Generally, the information requirements for separate identification of such activities have been found to be prohibitive (see Chapter 3, Section 4.3.2, Leontief (1970) and Leontief & Ford (1972)). Schäfer & Stahmer (1989) attempt to introduce pollution abatement activities in the manner proposed by Leontief (1970) by identifying an 'environmental protection services' sector in their economy (the Federal Republic of Germany). This sector consists of private enterprises and government institutions supplying both services, such as sewage treatment, waste disposal etc, and inputs that a firm may use in carrying out its own abatement activities, such as cleaning materials. Also identified is an additional final demand category of 'fixed capital formation for environmental protection services'; this category is separately identified because cleaning and protection activities tend to be capital intensive requiring significant levels of fixed capital formation (e.g. through purchases of capital equipment).

However, all the other IO models I review in Chapter 3 limit their attention to issues relating to patterns of energy use and pollution generation. This tends also to be true of the CGE models reviewed in this chapter. Nonetheless, several CGE models do attempt to incorporate the type of environmental protection services that I have identified above.

One model, Nestor & Pasurka (1995a,b), uses the IO framework constructed by Schäfer & Stahmer (1989), incorporating the 'environmental protection services' sector and the 'fixed capital formation for environmental protection services' category of final demand to build a CGE model of the Federal Republic of Germany economy. They explain that this approach is possible in their case because of the availability of data on the exact inputs used by German industries for environmental protection, but that this may not generally be the case because of data limitations regarding environmental protection activities in many economies.

The modelling of the environmental protection sector is explained in Nestor & Pasurka (1995a)¹⁴. They follow the convention adopted by Schäfer & Stahmer (1989) in 'externalising' environmental protection activities and expenditures, whereby any 'internal' environmental protection activities carried out by polluting firms themselves (i.e. as ancillary activities, analogous to administration or R&D) are transferred to the (external) environmental protection sector. This involves reorganising the IO data base by transferring any inputs associated with internal environmental protection activities carried out in the (fourteen) production sectors of the economy to the column in the IO table that represents external environmental protection activities (the fifteenth sector). Thus it is possible to assume that the technology to abate pollution is separate and distinct from the technology used to produce economic goods and services. Put another way, by isolating environmental protection activities in this manner, these can be modelled as 'end-of-pipe' pollution abatement activities that do not affect production activities in the economy.

Nestor & Pasurka (1995a,b) model the consolidated environmental protection services sector as an artificial government sector, which they refer to as an 'agency'. This 'agency' collects abatement expenditures from polluting industries as an environmental production 'tax', using the revenues to hire the intermediate inputs and primary factors needed to provide environmental protection services. However, like Schäfer & Stahmer (1989), Nestor & Pasurka (1995a,b) are solely concerned

with the *economic impacts* of environmental regulations which involve firms and households undertaking a given amount of pollution abatement. They do not model the *generation* of emissions as a result of economic activity, and thus do not attempt to model the use of abatement technologies as a method of reducing emissions.

Two of the other CGE models reviewed here *do* model pollution abatement technologies as a method of reducing emissions. In Section 5.2 above, I note that a third option for reducing pollution (as an alternative to altering input use and/or output levels) in the models of Bergman (1990, 1991) and Beauséjour *et al* (1994, 1995) is to use emissions abatement technologies if they exist and are economically feasible. However, neither of these models adopts the approach of identifying a separate environmental protection sector – instead they introduce abatement services as a separate form of capital. I have said above that the Leontief approach to modelling pollution abatement activities via an environmental protection services sector (the approach adopted by Nestor & Pasurka, 1995a,b) is heavily dependent on detailed data regarding the exact inputs used by industries for environmental protection activities. These data may not be readily available in many economies, with the implication that modelling pollution abatement activities will be difficult, if not impossible. Nestor & Pasurka (1995a,b) note that this has led to other models adopting a simpler approach. This may explain why Bergman (1990, 1991) and Beauséjour *et al* (1994, 1995) model pollution abatement services simply as a distinct form of capital services.

In both these models, since capital is assumed to be the sole factor input to abatement activities, the marginal cost of abatement is taken to be equal to the cost of capital services for this purpose. Since there is no private return on undertaking abatement activities, there is no private demand for abatement capital in the absence of pollution policy. Where pollution policy does exist, firms will choose to undertake abatement activities if the marginal cost of an additional unit of abatement is less than or equal to the cost incurred in emitting an additional unit of pollution. For example, in Bergman's (1990, 1991) model pollution policy takes the form of an

¹⁴ The assistance of Carl A Pasurka of the US Environmental Protection Agency in supplying me with

The importance of modelling both direct and indirect energy-use and pollution generation by households is highlighted in a number of the IO modelling studies discussed in Chapter 3. As a result of their direct consumption of energy, mainly to run cars and heat and light homes, added to the indirect energy consumption embodied in most purchased goods and services, private households are important contributors to the environmental problems that have motivated the increased use of economic-environmental modelling. This implies that modelling the energy- and pollution-related consumption behaviour of households is likely to be as important a factor in constructing environmental CGE models as modelling these factors on the production side. I would stress that in many economies this will be true of a number of final demand groups – for example, in Chapter 6, where I begin constructing a model for Jersey, I focus on the importance of direct emissions by tourists. However, I would argue that, in general, direct energy use and pollution generation by final consumers does seem to be an area that is neglected in most of the existing models reviewed here.

6.1 Modelling The Consumer Decision Making Process

Conrad (1999) explains that the usual approach in CGE models is to assume that consumers perform a multi-stage budgeting procedure:

1. At the first level inter-temporal consumer behaviour allocates a lifetime wealth endowment across consumption in different time periods.
2. Then at the second level there is an intra-temporal choice between leisure (supply of labour) and consumption.
3. At the final stage consumption is then allocated among a number of consumption goods/categories.

Within this general framework, Conrad's (1999) survey finds several different ways of specifying the consumption decision, the most frequent being the use of linear

expenditure system (LES), nested CES or translog demand functions. He also finds that most studies focus on efficiency issues, with all consumers aggregated into a single representative consumer. However some studies use household disaggregation, modelling several different types of consumer, in order to assess the distributional impacts of different environmental policy options. I discuss this second issue separately in Section 6.2.

The models reviewed in this chapter can generally be described within Conrad's (1999) framework, with some exceptions. Firstly, most of the models I review here are not inter-temporal optimisation models, so the first level described above tends to be a decision between consumption and saving, with savings generally being some fixed proportion of income in any given time period. Savings is generally listed as one of the available consumption goods or categories and its price relative to other (present) consumption choices is determined as the expected future return to capital. In static single- or multi-period (recursively dynamic) models this is generally taken to be equal to the current return to capital.

The second deviation from Conrad's (1999) framework occurs in models such as that of Conrad & Schröder (1991a, 1993), where labour supply is taken to be exogenously determined, implying that no demand for leisure is explicitly modelled. Where this is the case the consumption choice collapses to one between future consumption (savings) and present consumption, the latter being the choice between different consumption goods/categories.

Several of the models that I review here – Depotakis & Fisher (1988), Bergman (1990, 1991), Conrad & Schröder (1991a, 1993), Beghin *et al* (1995), Welsch (1996), and Naqvi (1998) – adopt a linear expenditure system (LES) specification to represent consumer demand. The main idea behind using LES is to get over a limitation imposed by using CD and CES functional forms for utility functions: the implication of unitary income elasticity of demand for each consumption good. While in the case of the production function this restriction is desirable where constant returns to scale is a required property, the same cannot generally be said

when it comes to utility functions. Therefore functional forms that impose unitary income elasticity of demand will only really be suitable when dealing with systems where average incomes are expected to remain unchanged. This will be the case, for example, if any change in income arises purely from a change in the number of households (which may be appropriate when looking at questions involving migration). If average incomes *are* expected to change in response to some disturbance to the system, LES offers an alternative demand system that does *not* impose unitary income elasticities.

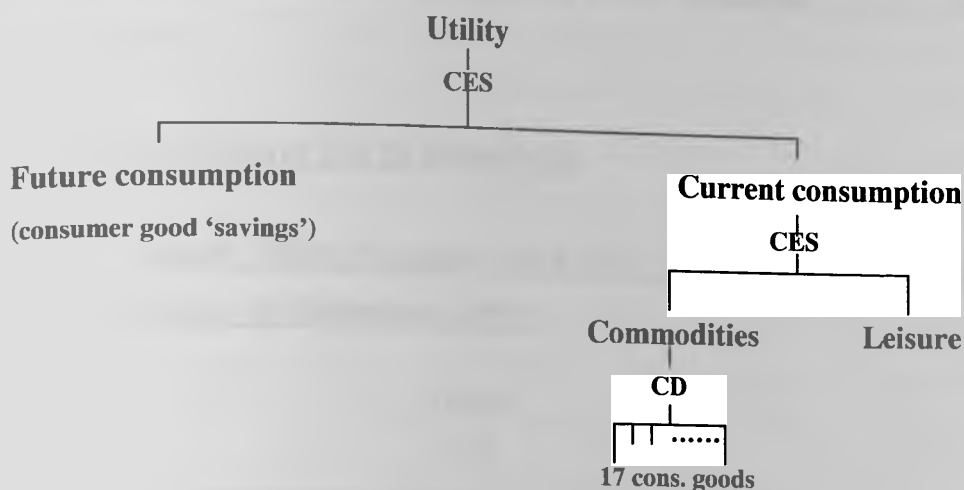
The LES takes the form (taken from Deaton & Muellbauer, 1980, and using their notation):

$$(4.9) \quad p_i q_i = p_i \gamma_i + \beta_i (x - \sum p_k \gamma_k)$$

Where x is nominal income, β_i is the share in non-necessity expenditure and γ_i is the subsistence level of consumption for each consumption good, i . The quantity consumed of each good, q_i , is greater than the subsistence level. The problem then is choosing values for the subsistence parameters that lead to reasonable values for the income elasticities (these may be taken from econometric estimates).

The models reviewed here that use LES demand systems do not generally provide a great deal of detail on precisely how they employ this approach. However to cut down on the number of explanatory variables in an LES system like that given in equation (4.9), models like Burniaux *et al*'s (1992) GREEN group consumption goods into a smaller number of aggregate consumption goods (e.g. food & beverages, fuels & power). They note that, at this first level, their model of consumer demand allows for different income elasticities across consumer goods. However, within these aggregate groupings Burniaux *et al* (1992) use CES/CD/Leontief nested relationships to determine the mix of individual consumption goods making up each aggregate, implying differing price elasticities of demand across different consumer goods (via separability assumptions) but constant income elasticities of demand.

Figure 4.7 – Nested Utility Function Used For Household Consumption Decisions In Borges & Goulder (1984)



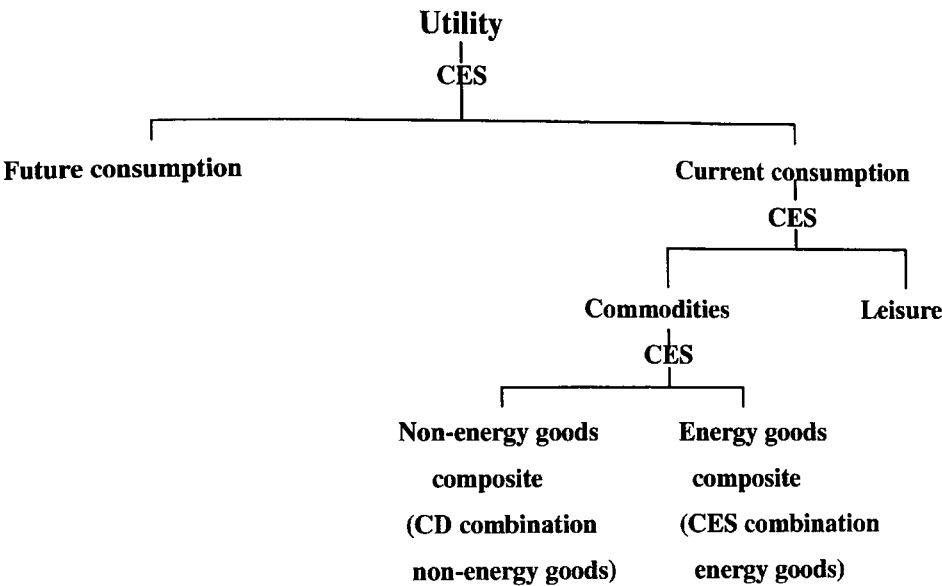
However, the largest proportion of the models that I review here simply model consumer preferences/utility using a nested CES/CD/Leontief specification, implying that the imposition of unitary income elasticity is accepted for the systems being modelled. These models are Morgan *et al* (1989), Boyd & Uri (1991), Stephan *et al* (1992), Beauséjour *et al* (1994, 1995), Goulder (1995), Weise *et al* (1995), Böhringer & Rutherford (1997), and Kamat *et al* (1999). Generally, with the type of exceptions noted above regarding savings and leisure decisions, the nested structures used describe the type of multi-stage budgeting process identified by Conrad (1999) (see above). For example, in Figure 4.7 I illustrate the nested utility function employed by Borges & Goulder (1984).

As I note above, most of the models reviewed here are not inter-temporal optimisation models, with ‘future consumption’ meaning ‘savings’ as one of the available consumption goods, which generally enters the utility function at a different level to the other available consumption goods. Typically the categories of available ‘consumption goods’ differs from the list of outputs of the producing sectors, but are linked via some kind of transformation matrix which converts demand for consumer goods and services into demand for producer goods, and computes prices of consumer goods from producer prices. Note that, while it is not

illustrated here, for each consumption good there are generally further CES nests in the consumption decision for the choice between domestically produced and imported goods for each commodity, just as is in the production decision (see Section 4.2.2 above).

6.2 Modelling Direct Energy Use By Households

Figure 4.8 - Nested Utility Function Used For Household Consumption Decisions In Böhringer & Rutherford (1997)



While indirect energy-use and pollution-generation by consumers is embodied in most of the consumer goods, and can therefore be traced back from consumption decisions, in most of the models I review here there is also direct energy-use by households through consumption of goods like electricity, oil, gas etc. However, the possibilities for substitution between different types of energy and non-energy commodities differ across the models. Some of the models incorporate an energy group – i.e. giving an energy aggregate or composite energy good - as part of the consumption structure. For example, in Figure 4.8 I illustrate the utility function adopted by Böhringer & Rutherford (1997). Note that this has the same structure as the one illustrated in Figure 4.7 for Borges & Goulder (1984) except for the fact that

Böhringer & Rutherford (1997) distinguish between energy and non-energy consumption goods.

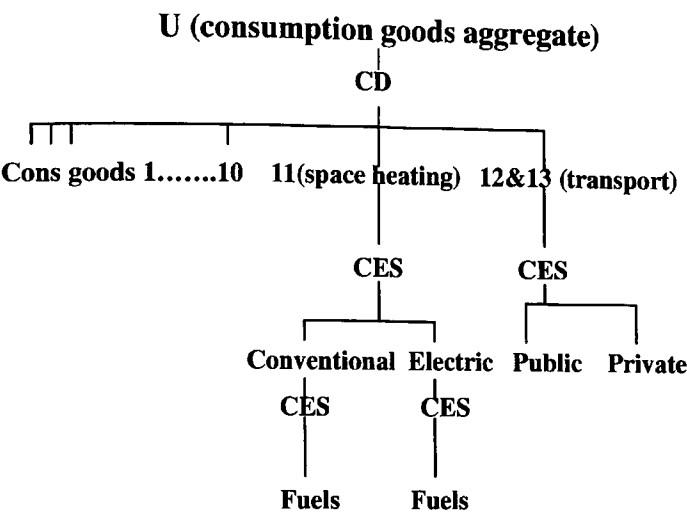
Beauséjour *et al* (1994, 1995) also allow multi-level substitutions between different energy and non-energy consumption goods. They model the energy choice in exactly the same way as it is modelled in their production structure – see Figure 4.6 above (Section 4.1). However, as I explained in my discussion of the production structure employed by Beauséjour *et al* (1994, 1995), motor fuels, which is likely to be an important energy source for households, is not separated from other intermediates into an energy aggregate. Instead a ‘stationary energy’ aggregate is separately identified, encompassing the types of energy that will be used in final consumption for non-transport, mainly heating and lighting purposes. Motor fuels combine with ‘other intermediates’ at the level below combination with this energy aggregate. Presumably this is because the motor fuels and stationary energy types are used in quite distinct activities (transport and heating/lighting respectively), with the implication that substitutability between them is likely to be low.

In fact the characterisation of the consumption choice in Beauséjour *et al* (1994, 1995) mirrors the production structure for *all* intermediates. That is to say, the *structure* of intermediate input use illustrated in Figure 4.6 can be re-labelled as the consumption goods aggregate in Beauséjour *et al*’s (1995) utility function (the values of the coefficients will differ from those in the production structure).

However, most of the models that I review here do not specify a separate energy goods aggregate, or model separate substitution possibilities between different energy goods. Instead the general approach is to adopt a consumption structure of the type illustrated in Figure 4.7 for Borges & Goulder (1984), with a CES or CD relationship between all consumption goods at the same level. This, of course, has the implication, highlighted by Boyd & Uri (1991), that the elasticity of substitution between any pair of consumption goods/services must be the same. Boyd & Uri (1991) describe this as a CES relationship, but note that, due to a lack of reliable estimates for these substitution elasticities, they are all assumed to be equal to one. I

interpret this as meaning that their CES function collapses to the CD one assumed in most of the models with single level modelling for the consumption good aggregate (however it seems odd that CD is not simply specified by Boyd & Uri (1991), since CES is undefined for $\sigma = 1$).

Figure 4.9 – CO₂-Related Substitution Possibilities In Stephan *et al* (1992)



One model that does allow another level of substitution possibilities within the consumption goods aggregate is Stephan *et al* (1992), which focuses on the main sources of CO₂ emissions in private consumption, which they identify as traffic and space heating. Through CES sub-nests of their CD utility function, they explain that consumers can substitute between (a) public and private transportation (identified as distinct consumption goods), and (b) in the case of space heating, both between different fuels, and between conventional and electric heating systems.

In addition to the question of substitutability between different types/categories of consumption good, Conrad & Schröder (1991a, 1993) highlight another important issue, one that is not addressed in any of the other models I review here: modelling the effect of some durable and non-durable goods being *complements* in consumption. For example, the imposition of taxes on CO₂ emissions resulting from the combustion of fossil fuels by private road-users will affect the use and demand for cars. Similarly, emissions taxes on the generation of electricity will affect the

price of electricity to consumers, and hence their use and purchase of electric appliances.

Conrad & Schröder's (1991a, 1993) model of consumer behaviour consists of 3 durables (cars, heating and electric appliances) and 20 non-durables as given by the IO tables, in a linear expenditure system. Three of these non-durables - gasoline, electricity and heating energy – are linked to the stock of durables as complements in consumption. Conrad & Schröder (1991b) argue that using a FFF in the demand system could capture the notion of complementarity between durable and non-durable consumption goods. This would involve negative cross-price elasticities of demand for the goods that are complements in the same way as some of the models I review here do for the production system with complementary inputs. (Equally, then, I would again argue that an alternative option would be to attempt to capture this complementarity in a Leontief relationship in a CES/CD/Leontief consumption structure of the type already discussed above for a number of the models reviewed here.)

Generally, Conrad & Schröder (1991b) argue that, since only part of the consumption of a non-durable good may be regarded as essential for the operation of a durable good, it is necessary to improve on the type of demand structure commonly used in environmental CGE models. To explain their approach, Conrad & Schröder (1991b) give the example of the non-durable good gasoline, which they assume is consumed only to operate the durable good cars. Some of the demand for gasoline will be for the essential operation of the car. This consumption of gasoline is only substitutable for other consumption goods in so far as the car is substitutable for other goods, and its market price is referred to as a cost price, which is linked to the stock of the car(s) owned by the household. However Conrad & Schröder (1991b) argue that the consumer may derive utility from purchasing more than the essential amount of gasoline required to operate the car in order to indulge in “sportive and high-speed” (p.275), or “unnecessary” (p.273), driving. This part of gasoline consumption they regard as variable (not linked to the household stock of car(s)) and substitutable with other consumption goods independently of the durable good. For

this reason the demand for gasoline is decomposed into a variable (substitutable) part and a non-variable (non-substitutable) part that is linked to the stock of the complementary durable good (cars). In terms of the demand for the durable good (cars), optimal stocks of all durable goods are derived from an “intertemporal minimisation of expenditures” (Conrad & Schröder, 1991b, p.273). These expenditures consist of expenditure on the non-durables required for operation purposes, purchases of new durables as net investment, or for replacement purposes, and of taxes on durables. Therefore, with respect to other consumption goods, the demand for the non-durable good, cars, depends both on its own price (including taxes) and on the price of the linked non-durable good, gasoline (including any taxes on gasoline), as well as the price of any consumption goods that are substitutes for cars. The demand for gasoline depends on the price of gasoline, the price of the linked durable good, but also in (the non-linked) part on the price of all other consumption goods.

A full account of the approach to modelling the demand for durable and non-durable goods adopted in Conrad & Schröder (1991a, 1993) is given in Conrad & Schröder (1991b). The reason for my inclusion of this brief outline and discussion of their approach is that the argument regarding the importance of recognising the link between the demands for durable and non-durable goods is an entirely valid one. However, it is not clear to me why this could not be handled in a more standard consumption structure by extending the disaggregation of non-durable goods such as gasoline into different ‘types’ for essential and recreational (non-essential) purposes. Moreover, all the arguments concerning testing of model specification in production (Section 3) apply in the case of consumption also.

6.3 Distributional Analysis

The final issue raised by Conrad (1999) is whether studies focus on efficiency issues, with all consumers aggregated into a single representative consumer, or whether there is disaggregation into several different types of household in order to assess the distributional impacts of, for example, different environmental policy options. In

addition to differential distribution effects, it is also likely to be the case that patterns of consumption will vary significantly across income groups, with the implication that, among other things, the environmental impact of the consumption activities of different households will vary. Household/consumer disaggregation allows analysis and identification of which types of household contribute most to environmental problems, as well as distributional analysis to identify which households suffer the greatest economic impact from environmental policy actions.

However, as found by Conrad (1999), the majority of the models that I review here assume a single representative consumer/household. Nonetheless a growing number of environmental CGE models do incorporate household/consumer disaggregation in order to address the type of issues raised above, generally differentiating households by income, expenditure and/or demographic categories. All the models reviewed here that incorporate household disaggregation - Borges & Goulder (1984), Boyd & Uri (1991), Stephan *et al* (1992), Weise *et al* (1995), Naqvi (1998) and Kamat *et al* (1999) – do so by allocating households into income bands.

Classification of households by income categories would appear to be the most common method of household disaggregation. However, where data permit, households should ideally be disaggregated to identify different demographic rather than income groups. This is because the latter will be variable if income is determined endogenously. For example, in one of the earliest (econometric) environmental CGE models, Jorgenson & Wilcoxon (1993) identify 672 different types of household, defined by a number of demographic classifications. Naqvi (1998) attempts to introduce non-income classifications, allocating households to groups relating to employment and regional location within the defined income bands. Weise *et al* (1995) go one step further, mapping individuals to households to account for multiple job-holders and multiple earners in any one household, arguing that this is important for proper in-depth distributional analysis.

Where households are disaggregated by income, Weise *et al* (1995) argue that this should be done using income *bands* (e.g. £10,000 - £20,000, £20,000 - £30,000 and

so on) rather than breaking the population into equal-sized groups (e.g. into quintiles or deciles). They explain that this is because the latter method tends to result in over-aggregation of important groups (such as high earners). This of course will depend on how many households are likely to fall into different classifications. All of the models I review here that incorporate household disaggregation according to income do appear to do so by income *bands*. In fact, Weise *et al*'s (1995) point is illustrated in Stephan *et al*'s (1992) model of Switzerland, where 66% of the population are captured in the lowest income band, with the highest three income bands containing only 10% of Swiss households in total. Stephan *et al* (1992) are concerned with the effects of varying responses of different households to changes in relative prices brought about by a carbon tax, due to the varying inclination of different income groups to substitute away from private transport towards public transport. These are the type of effects that Weise *et al* (1995) argue may be hidden if distinct income groups are not identified in the disaggregation process.

My conclusion is that the important issue, whether income or non-income criteria are used, is determining the homogeneity of households that are classified together in one household group. The general approach observed here is to specify distinct preference structures/demand systems for each income band (meaning that preferences, and the timing of consumption choices, are taken to be function of income). Thus, in grouping households in a given demographic or income band, it will be important to attempt to ensure that consumption preferences are in fact fairly homogenous among the households contained therein. (Note that in the models I review here, the differences in preferences and demand across different income bands are generally modelled via differences in elasticity of substitution parameter values, rather than by having distinct structures for consumption decision process for each type of consumer.)

One of the key issues that Boyd & Uri (1991), Stephan *et al* (1992) and Naqvi (1998) focus on is whether the type of results found in partial equilibrium analysis of energy/fuel taxation – i.e. that such taxes are likely to be regressive - carry over to a general equilibrium analysis. This is one of the most important questions associated

with distributional analysis and sustainability policy concerns – whether the burden of environmental taxes is unfairly borne by low income groups, since essential expenditure on energy/fuel is likely to account for a larger proportion of their income. However, in contrast to what is commonly reported from partial equilibrium analyses, the general equilibrium results of Boyd & Uri (1991), Stephan *et al* (1992) and Naqvi (1998) all suggest that the distributional effects of various energy taxation changes are minimal. Boyd & Uri (1991) explain that this does not imply that the direct effects of, in their case, an increase in fuel taxes are not regressive. Rather they explain that, mainly because of changes in relative prices, in a general equilibrium setting indirect effects are likely to mean that such a tax increase may not, on balance, be a regressive one in terms of the redistribution of the tax burden. I will refer to these results again in Chapter 7, where my attribution of pollution generation based on different household income bands for Jersey suggests that the *direct* impact of energy taxes is likely to be regressive.

Weise *et al* (1995), whose paper is the only one of those I review here that focuses specifically on distributional issues (in the context of motor fuel taxes and household welfare), identify what appear to be the two most important influencing factors in a distributional analysis. The first is what happens to energy/fuel tax revenues – i.e. how these are redistributed/spent by government. Weise *et al* (1995) consider several different expenditure patterns for fuel tax revenues and find that the distributional effects are conditional on what government does with increased revenues. How the revenues are spent will impact on what Weise *et al* (1995) identify as the second key factor in determining distributional effects: the different sources of income available to different income groups. They find that the distributional impacts of energy/fuel taxes depend on whether the tax change *and* expenditure of revenue lead to increased or decreased rates of return to capital and skilled labour services, which are important sources of income for upper-middle and high income households. They report that, where the incomes of these households suffer from a decline in the rates of return to capital and/or skilled labour services, the distributional impacts of increased motor taxes tend to be smoothed out (or in some situations, are actually found to be progressive). Therefore, Weise *et al* (1995) conclude that to model

distributional effects properly attention should be given to how environmental tax revenues are redistributed back to households. Specifically, they argue that the key issue is whether revenues are used to purchase goods and services, capital and labour, and to the different sources of income (and factor endowments) of different households.

7. Chapter Summary And Conclusions

The purpose of this chapter is to identify and consider issues that are likely to be important in constructing an environmental CGE model. Given that the aim of the current project is to construct an environmental CGE model for a single small open economy, the first issue discussed is the nature of the effects that we should hope to be able to capture. In Section 2 I explain how, in the case of a model based solely on data for a single small regional economy, it is necessary to adopt the ‘small open economy assumption’. This means only attempting to model the target (local) economy with the rest of the world assumed to be exogenous. The key implication of this, in terms of economic-environmental modelling, is that it is not possible to take account of any feedback effects from the global environment to the local economy resulting from disturbances in the latter. In other words, while it is possible to assess the economic effects of global environmental policies on the local economy, it is not possible to assess any environmental feedback effects resulting from any consequent improvement in the global environment. However, by employing the small open economy assumption, what we are saying is that we assume that these feedback effects would be so small (because the target economy is so small relative to the rest of the world) that they can be considered negligible.

In Section 2 I also argued that another implication of the target economy being a small open economy is that issues like modelling resource depletion are not likely to be relevant. My argument is that resource depletion will only be an issue in modelling a small open economy if the resource in question cannot be easily imported from elsewhere in the world. The main way in which natural resource issues will enter into such a model will be in addressing problems of resource

constraints and/or the effects of resources prices that are set elsewhere in the world (i.e. exogenously).

In Section 3 I go on to consider issues that have been identified in the literature as being important in modelling energy use, which is the main source of environmental problems that are attributable to economic activity. A number of important issues are discussed, including the question of whether energy is a complement or a substitute for other factors of production, and appropriate functional forms. However, my main conclusion is that, while many important arguments have been put forward for how production involving energy use should be modelled, none of the models that I review here properly addressed the issue of model specification by actually testing a full range of alternatives. I note that sensitivity analyses were largely limited to parameter values, not to the production structure itself. This conclusion will also apply to the discussion of consumption structures in Section 6. Nonetheless, my arguments on this issue are qualified by the admission that such an ideal approach to model specification is likely to be highly resource intensive and not feasible in practice. However, the main point I wish to make is that, while it may not be practical at this time to overcome this problem of the judgmental nature of model specification in CGE applications (or any type of complex system-wide model), the problem should be considered explicitly when assessing alternative specifications.

In Section 4 I review the literature to examine how the problem of modelling production with energy inputs has been approached in existing models of economic-environmental interactions. As well as illustrating the points made above with respect to model specification, my survey highlights the fact that there is a great deal of variability across existing models in terms of what individual energy types are identified and how they enter into the production structure. My main conclusion here is that the detail and nature of energy modelling is very much case dependent – i.e. the detail of energy modelling depends very much on the nature and structure of the specific economy being modelled, and most likely on the availability of appropriate data for this purpose.

In Section 5 I move on to the question of modelling pollution, where many of the same type of issues arise. In terms of what pollutants are modelled, I again conclude that this tends to depend on the specific economy being modelled and the purpose of building the model – i.e. whether the focus is on global or local environmental concerns, on specific types of policy etc. I argue that the main model specification issue is whether pollution is related to inputs to or outputs from production. If there are opportunities for reducing emissions through input substitution (i.e. if production technology is sufficiently variable), it is necessary to model input-pollution relationships in order to quantify environmental impacts. For example, if we want to assess the implications of changing/imposing energy taxes such as carbon taxes, then it is necessary to directly model the relationship between input use and pollution. This is because the aim of this type of tax is to induce substitution away from polluting inputs (by affecting relative prices). Therefore, input-pollution coefficients will be necessary if this type of policy is being model if we want to capture any consequent change in the output of pollution. I explain how this may become a somewhat complex task if emissions resulting from input use depend on combustion conditions and technology, particularly if multiple, non-CO₂, pollutants are involved. I also stress the importance of recognising that not all emissions in the economy in question will be directly related to input use, since many production processes involve non-combustion related emissions generation.

In Section 6 I focus on how the consumption side of the economy is specified in the models reviewed. In terms of issues relating to the appropriate choice of functional forms and how energy use and pollution generation are modelled, I find that the same type of issues arise as in the case of production. I argue that the main consumption-specific issue, particularly if the model is intended to analyse sustainability questions, is the scope for distributional analysis. My conclusion is that, while a number of the models reviewed do attempt to address distributional issues by incorporating household disaggregation according to income, clearly this is an area that has not yet received a great deal of in-depth attention in the environmental CGE literature. Nonetheless some important modelling issues are identified, such as the importance of the sources of income available to different households.

The rest of my dissertation focuses on constructing an empirical model of economic-environmental interaction, using the Jersey economy as a case study. Throughout this process I draw on the general lessons learned in the literature review conducted in Chapters 3 and 4. In Chapters 5 and 6 I focus on constructing an economic-environmental database that can be used for a wide range of possible model specifications. Some basic analyses using the simplest variant of the economic-environmental modelling framework constructed here, an environmental IO system, are conducted in Chapter 7. In Chapter 8 I move on to the task of model specification and calibration for the less restrictive CGE configurations of the economic-environmental model of Jersey. Some illustrative simulations using the model are conducted in Chapter 9.

Chapter 5. Economic Database Construction

1. Introduction

I have attempted to identify the general lessons to be learned from the literature about economic-environmental general equilibrium modelling in Chapters 3 and 4. Therefore, I now turn my attention to the process of constructing an empirical CGE modelling framework for a specific economy, in this case the small open island economy of Jersey.

The process of model construction can be considered in terms of Shoven & Whalley's (1984, p.1019, Figure 1) 'calibration procedures and model use', which are introduced in Chapter 3 (Section 3.2) for the limiting case of IO as:

1. Base year data collection
2. Organisation of the benchmark equilibrium data set
3. Choice of functional form and calibration to benchmark equilibrium. In a CGE context this third stage incorporates three distinct elements:
 - (a) Model specification
 - (b) Specification of exogenous parameter values
 - (c) Calibration of remaining parameter values to replicate initial equilibrium conditions
4. Analysis using model

The general equilibrium framework that I am constructing here is intended to incorporate a range of modelling options, from the limiting case of IO to a number of more flexible CGE model configurations. In this chapter and the next I focus on the first two stages – data collection and organisation of the benchmark equilibrium data set – for all possible model configurations within the general equilibrium framework for Jersey.

There are four basic data requirements for the construction of an economic-environmental CGE modelling framework:

- (i) Base year input-output (IO) tables for the target economy
- (ii) Social accounting matrix (SAM) for the target economy (incorporating the IO tables and other information on income flows between the main institutional transactors)
- (iii) Other structural data for the target economy (including base year labour market data and investment demands)
- (iv) Base year economic-environmental accounts and pollution coefficients

Element (i), construction of an IO table for the base year, is the core common requirement to model the economy within a CGE framework. To move beyond the limiting case of IO, elements (ii) and (iii) are also required. Therefore, my objective in the current chapter is to construct a database incorporating all these elements for Jersey in 1998 (the chosen base year for the current project). Element (iv) is what is required to turn the basic economic model into an economic-*environmental* model. This is discussed in the next chapter (Chapter 6). Then, in Chapters 7 and 8 I turn my attention to model specification and parameterisation for the limiting case of IO in Chapter 7, and for the more flexible range of CGE options in Chapter 8. I also present analysis using the model – Shoven & Whalley’s (1984) stage 4 –in Chapter 7 for the environmental IO system. The final stage my dissertation is the illustrative economic-environmental CGE analysis for Jersey, which I report in Chapter 9.

2. Economic Database Requirements

I note above that the core database for CGE modelling is a Social Accounting Matrix (SAM) for the target economy, augmented with additional information on employment and investment to describe the structure of the economy in the base year to which the

model will be calibrated¹. The notion of organising sectorally detailed data on the production and exchange of commodities, and consumption and investment in the economy in a suitable framework for economic analysis and planning can be dated back to the first publication of 'The Social Framework' (Hicks, 1942). Hicks (1942) explains that, in order to address questions about how the economy functions, one must first have an understanding of the relevant economic theory. However, he argues that an equally important requirement is the construction and understanding of a comprehensive and appropriately organised database describing the structure of the target economy. He refers to this second element as "Social Accounting...accounting of the whole community or nation, just as Private Accounting is the accounting of the individual firm" (Hicks, 1960, p.vi²).

Building on the work of Hicks (1942), and subsequent efforts to establish concepts and standards for national income accounting, many analysts (particularly development economists³) have promoted the organisation of relevant and available data in a single entry matrix format, commonly referred to as a social accounting matrix (SAM). (Pyatt & Round, 1985a).

A SAM generally contains detailed information describing the production structure of the economy. That is to say, how income is generated in the economy. It also contains information on flows of income and patterns of consumption expenditure and capital formation within the economy, subdivided by the main economic transactor groups (e.g. households, firms, government and foreigners). In other words, how the income generated in the economy is distributed.

¹ If my intention were to construct a full econometrically estimated CGE model, a time series of SAMs for the target economy would be required. If it is decided that econometric estimation is to be carried out for the target economy this will influence the data collection process. However, in the case of Jersey this is not a decision that I face because appropriate data for econometric estimation are not available.

² Hicks (1942) considered the importance of developing and understanding the practice of social accounting as a precursor to applied economic analysis to be such that he undertook a "plan" (Hicks, 1960, p.vi) to revise and reprint his book 'The Social Framework' every ten years in order to remedy any defects. At least four editions (in 1942, 1952, 1960 and 1971) have been published on this basis.

Data on the structure of production and consumption expenditure can generally be obtained from the economy's input-output accounts, which now tend to be constructed as a central part of national accounting in most industrialised economies. This means that in order to construct a SAM all that is normally required is additional information on flows of income between the main economic transactors.

Unfortunately, pre-existing IO accounts are *not* available in the case of Jersey where comprehensive national accounting has not been routinely carried out before now. However, the current study is part of a wider project involving the construction of a set of national accounts for Jersey on the basis of its first IO table (constructed by the Fraser of Allander Institute, 2001a) and a SAM for the most recent year possible, 1998.

While having to fully construct the modelling database in this way is highly resource intensive, doing so offers the benefit of being able to collect and process data in a way that is most consistent with the requirements of the current project. For example, in Chapter 3 (Section 5.2) I explain that many economic-environment models cite a lack of key energy-use data in national (IO) accounts as a critical problem⁴. However, as I explain in this chapter, in the Jersey case it has been possible to tailor the data collection process specifically to tackle this difficulty.

In terms of the IO accounts, I was not involved in the data collection process outlined in Section 3.1 below, my involvement beginning at the data processing and balancing stage (Section 3.2). However, while I have not had primary responsibility for constructing the standard IO table for Jersey, I have been responsible for making revisions and adjustments to reflect better energy supply data that did not become available until after the preliminary IO accounts had been presented to the States of Jersey. I have also had primary responsibility for constructing the SAM presented here (see Section 4 below).

³ See the World Bank Symposium on social accounting matrices (edited by Pyatt & Round, 1985a – country studies included in the Symposium are reviewed in Pyatt & Round, 1985b).

In summary, I take the first stage in the process of (economic) data collection and organisation (Shoven & Whalley's (1984) procedures 1 and 2) to be the construction of an IO table for the chosen base year. In Section 3 of this chapter I explain the construction of an IO table for the Jersey economy in 1998. It is possible at this stage to move directly to the simplest type of general equilibrium modelling, IO analysis. However if I want to be able to do more ambitious CGE modelling (or extended IO modelling in a SAM framework⁵), it is necessary to augment the IO database with information on flows of income between the main transactor groups – households, firms, government and foreigners. This second stage of the economic database construction involves development of a SAM for the target economy for the chosen base year. In Section 4 I explain the construction of a SAM for Jersey in 1998. Finally, to complete the base year dataset required for CGE modelling, I add data on the supply-side of the labour market and investment. Incorporation of these additional data to the economic database for Jersey is discussed in Section 5. In Section 6 I provide a summary and conclusions relating to the construction of the economic database.

3. Construction Of The Jersey IO Table For 1998

As noted above, I did not have primary responsibility for constructing the IO accounts for Jersey. Therefore the work reported in this section has been carried out in conjunction with other members of staff at the Fraser of Allander Institute.

3.1 Data Collection

There are typically three main sources of data for the construction of an IO table:

⁴ See for example Gale (1995), Hawdon & Pearson (1995), Lange (1998) and Lenzen (1998).

⁵ See discussion of SAM-based attribution analyses in Chapter 7, Section 2.2.2

- Survey-based primary data: information gathered directly from surveys of local firms and households
- Non-survey primary data: local economic data, both published and unpublished, that have been collected by private and public sector organisations for a variety of purposes, but not specifically for the IO study
- Secondary data: non-local data that can be modified in accordance with local socio-economic characteristics to provide acceptable local estimates

The Jersey IO table is constructed using a mainly survey-based approach: because no previous IO tables exist for the Jersey economy it is important to get an initial database that is as accurate as possible. An industrial survey process was carried out by the Fraser of Allander Institute, focussing mainly on private sectors firms to estimate their primary and intermediate inputs demands and the destination of their output in terms of sales to other local firms, local households and government, tourists and other exports⁶. The States of Jersey provided information on production activities in the public sector, as well as household income and expenditure and tourist survey data. Information provided by the States of Jersey falls into the second category noted above – i.e. these are primary data, but which have not been collected specifically for the IO study – meaning that it is necessary to employ appropriate data reconciliation techniques to make these consistent with IO accounting conventions.

In total, including public sector activities, we have 36% coverage of total Jersey employment in the primary data collection process. For the production survey, firms in each sector are disaggregated by employment size band. Large firms are mainly targeted for personal interviews and the postal survey is aimed at smaller firms in an attempt to capture differences in the level of technology, dependence on and sourcing of intermediate inputs and the destination of outputs across firms of different size. Survey coverage varies across sectors, with relatively high coverage (40% or more) in sectors

such as finance and manufacturing, but poorer coverage in sectors like hotels, restaurants and catering and construction (20% or less). Where survey coverage is poor this tends to be because of difficulties in getting firms to comply (e.g. construction) and/or the composition of sectors in that it has proved difficult to make successful contact in sectors with a large number of small firms (e.g. hotels, restaurants and catering). However by using control total data from the States of Jersey and data from other local sectors that interact with those where survey coverage was poor it is possible to compensate for low survey coverage at the data processing stage.

3.2 Data Processing And Construction Of The Jersey IO Table (1998)

3.2.1 Structure Of The IO Table

First of all, the private sector firms and public sector organisations operating in Jersey are allocated to 28 SIC coded sectors⁷ according to their principal activity (I give a description of the SIC classification of the 28 sectors identified in Table 5.1). The sectorisation is determined by the objectives of the wider modelling project. In Chapter 3, Sections 2 and 5.2, and Section 2 of this chapter, I explain that, if the purpose of building a model is to examine economic-environmental interaction, the sectoral breakdown should be such that sectors with distinct energy use or supply and pollution characteristics are separately identified. The 28-sector breakdown is also the most extensive disaggregation of activities that is practical given the relatively small size of the economy and composition of activity therein. (Note that the IO table that can be presented here is actually aggregated to 25 sectors: this is due to the confidentiality constraints that will be discussed in detail in Section 3.3.)

⁶ A wider range of questions was actually included in survey questionnaires in order to elicit as much information as possible for the CGE database requirements. A sample questionnaire is shown in Appendix 5A.

⁷ The SIC coding system used here is the Jersey Standard Industrial Classifications (JSIC) 1995, published by the Chief Adviser's Office of the States of Jersey. The JSIC 1995 is based upon and consistent with the UK SIC (92) issued by the Central Statistical Office in 1992.

Table 5.1 Sectors Identified In The Basic (28-sector) Jersey IO table

No	Sector	UK/Jersey Standard Industrial Classification
1	Agriculture & Fishing	01,05
2	Quarrying	14
3	Manufacturing	15-18, 20, 22, 25-26, 28-31, 33, 35, 37
4	Electricity	40.1
5	Water	41
6	Gas	40.2
7	Jersey Telecommunications	64.2
8	Construction	45
9	Oil & Fuel Distribution	50.50, 52.48
10	Wholesale & Retail Trade	50-52
11	Hotels, Restaurants & Catering	55
12	Land Transport	60.2, 60.3
13	Sea & Air Transport and Transport Support	61,62,63
14	Jersey Post	64.1
15	Banks and Building Societies	65.121,65.21,65.22,65.233,65.234,65.235 & 65.236
16	Insurance Companies	66
17	Investment Trusts	65.231, 65.232
18	Fund Managers	67
19	Computer services	72
20	Legal Activities	74.11
21	Accountancy	74.12
22	Other Business Activities	70, 71, & 74.13 to 74.8
23	Other Service Activities	91,93
24	Recreation, Culture & Sport	92
25	Education	80
26	Health, Social Work & Housing	85
27	Public Services	90
28	Public Administration and Defence	75

The Jersey IO table also identifies 12 final demand categories:

- Household consumption, disaggregated into 5 income quintiles
- Gross domestic fixed capital formation (GDFCF)
- Changes in stock
- General government final consumption (GGFC)
- Exports to the UK, the rest of the EU (REU) and the rest of the world (ROW)
- Tourist expenditure

The five main primary factors are labour services, imports from UK, REU and ROW and other value added (relating to payments to capital and other property income). Also identified in the ‘primary inputs’ section of the table are production subsidies received (a negative entry) and expenditure taxes paid (in Jersey, where there is no VAT, these are simply taxes paid on goods and services imported by each production/final sector).

Figure 5.1 summarises the structure of the Jersey IO table.

Figure 5.1 Schematic Structure Of The Basic IO Table For Jersey, 1998

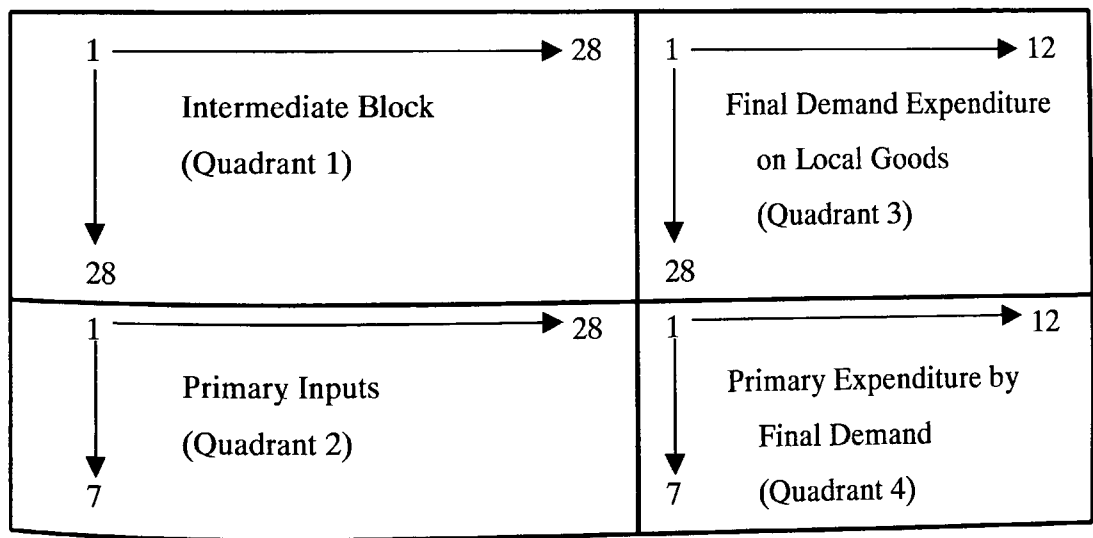


Table 5.2 Definitions Of Output Used In The Jersey I-O Table, By Sector

Sector	Definition
Primary, energy and manufacturing sectors	Output is the value of turnover plus changes in the value of stocks of finished goods.
Extraction/construction	Value of sales plus change in stocks plus value of work done.
Banking and Financial Intermediation.	Value of services (charges and commissions) plus net interest charges
Distributive trades, including fuel distribution, retail, wholesale etc.	Gross margins on sales plus direct service receipts. (Output is effectively calculated as total sales minus purchases for resale plus changes in stock.)
Private services	Value of receipts for services rendered. Hotels/catering output includes value of food and drink sold.
Public services, central government.	The total output of the Public Sector is valued at the costs of production, including intermediate consumption, compensation of employees, consumption of fixed capital and taxes (less subsidies) on production but excluding imputed rents of owned non-residential buildings and, by convention, interest payments.

3.2.2 Data Processing

We then process all the data gathered in the industrial survey and/or provided by the States of Jersey on public sector activities, household and tourist expenditure within the framework imposed by the intended 28-sector basic IO table. That is to say, data on all purchases (which will become column entries in the IO table) and sales (row entries) are recorded according to the SIC/IO categorisation of both the supplying/producing sector and the demanding/consuming sector.

Before proceeding to reconcile the data from alternative sources and ultimately to balance the table (to meet the identity that inputs must equal outputs at the sectoral and aggregate levels), we must first gross-up all the industrial survey data from the survey sample to the full population.

First, firms' responses on the value of their purchases of different inputs to production are grouped together first by the SIC coding of the purchasing firm's principle activity and then by employment size band⁸. Then the inputs they purchase are grouped together according to the SIC code of the supplying sector or the geographical source of imported materials (UK, REU or ROW), with wage payments allocated to a single labour category. With firms' responses on how much was paid in 1998 in expenditure taxes (import duties) and received in subsidies, the only 'primary input' we do not have information on is 'other value added' (payments to capital and other property income or profits). However other value added is treated as a balancing item: total inputs to production must equal total output, with total output estimated directly from the survey data (the definition and method of calculating gross output varies across sectors - see Table 5.2).

⁸ The four employment size bands are 0-25, 26-50, 51-100 and 100+ full time equivalent (FTE) employees.

We gross up the survey data on the basis of the share of sectoral employment (also disaggregated by size band) covered in the survey. Information on total employment by sector and size band are taken from the States of Jersey Manpower Database, which gives a very detailed breakdown of FTE employment by SIC code. The share of total employment covered in the survey is determined by dividing the sample employment by actual total employment for each sector and size band.

We conduct the grossing-up process as follows. First of all input requirement coefficients are calculated for each sector and size band, showing the value of each input purchased as a share of the gross sectoral output figure estimated from the corresponding survey data on sales. The sectoral output figure is then grossed-up by dividing it by the share of total employment covered in the survey to give total estimated sectoral output (for each size band). To get grossed-up estimates of input purchases, the new total estimated sectoral output figure is then multiplied by each of the input coefficients for each sector and size band in turn. (Alternatively survey returns on the value of inputs could be grossed-up directly based on the share of total employment sampled in the way described above for gross output: this would give the same results but is simply a more time-consuming process when there are multiple inputs).

3.2.3 Data Reconciliation And Balancing The IO Table

Once the industrial survey data have been grossed-up from sample to population estimates⁹, the next stage is to reconcile data from different sources. For example the survey data give us information on the source of firms' input purchases, which, once processed in the manner described above, give us estimates for the entries for each production sector's column in the IO table. The survey data also provide information on the destination of firms' output – other local businesses, households, tourists, RUK, REU and ROW demand – and how much goes to stocks and capital formation, all of

⁹ The household and tourist survey data were grossed-up by the States of Jersey before they were made available to us. The Public Sector data were based on 100% coverage of activity.

which gives us estimates for the entries in each production sector's row in the IO table. However, the household and tourist surveys also provide information on how much these final consumers say they actually spend on the outputs of local sectors. In some cases these responses differ from the estimates obtained by grossing up the industrial survey returns to obtain sales to households or tourist demand. Moreover, in some cases the grossed up survey returns on what local firms purchase from any one local production sector differs significantly from the survey estimate of what that sector sells to other local businesses. Where such discrepancies exist there is a need for data reconciliation. In constructing the Jersey IO table a number of basic procedures are followed to achieve a balanced table:

- Where it is possible to draw on reliable control total information from established sources within the States of Jersey this information is used to constrain the data reconciliation process. For example, in the case of the 'expenditure taxes' row, information is available on total import duties paid during the year in question, 1998. Since, as mentioned previously, import duties are the only type of expenditure tax in Jersey, this allows correction for any inaccuracies in the survey data.
- Control total information is also available for the gross outputs of several of the finance sectors – banks & building societies, investment trusts & fund managers and accountancy – from previously conducted surveys focussing on the finance sector. These alternative surveys have better survey coverage in terms of the number of firms covered, but lack the type of detail on input requirements needed for the IO table. However the estimates of gross sectoral outputs are judged to be more reliable because of the better survey coverage. The input requirement coefficients from the IO industrial survey are therefore applied to the finance control totals rather than the grossed-up sectoral output figures from the IO survey to establish the column entries for these financial sectors.

- In cases where there is have 100% survey coverage of activity in a sector – i.e. in the public sectors and utilities such as gas, where one firm constitutes the entire sector – it is obviously possible to be much more confident in the quality of the industrial survey data. This means that any discrepancies between estimates given by the producing sector and the purchasing sectors or final demanders are best handled through manual balancing of the producing sector's row and column.
- In other cases where discrepancies exist, judgement must be exercised with respect to which source is most reliable, taking into account overall balancing requirements in the table. (In particular, where earlier stages of data reconciliation have fixed the value of entries in a given number of cells this imposes internal consistency constraints on the assignment of values to the remaining entries).
- When we are satisfied that all possible attempts have been made to reconcile inconsistencies and manually balance the table, a computer-based balancing programme is utilised¹⁰. The main prerequisite in undertaking non-manual balancing is a high degree of certainty that the column totals for the 28 production sectors are correct (i.e. the total sectoral input requirements) as these are used as control totals in balancing the table.
- The final data check is to present the balanced table to a number of people in the States of Jersey and other interested groups who have sufficient local knowledge and familiarity with IO accounting conventions to carefully scrutinise the table entry-by-entry and identify any problems. This final stage in the data reconciliation and balancing process is crucially important for identifying errors and omissions and helps focus attention on problem areas: in the Jersey case two balanced versions of the table were presented before the acceptance of the final (third) version.

¹⁰ We apply software that is based on the RAS procedure originated by Stone (1961).

Table 5.3 An Industry By Industry Input-Output Table For Jersey, 1996 (£millions)

Sectors	Agriculture & Fishing	Quarrying & Construction	Manufacturing	Electricity	Water	Gas, Oil & Fuel Dist.	Jersey Telecom.	Wholesale & Retail Trade	Hotels, Rest. & Catering	Land Transport	Sea & Air Trans. & Trans. Supp.	Jersey Post	Banks & Building Soc.	Insurance Companies	Inv. Trusts & Fund Managers	Computer Services	Legal Activities	Accountancy	Other Business Activities	Other Services
Agriculture & Fishing	0.5590	0.0001	10.9600	0.0000	0.0008	0.0000	0.0008	0.3487	6.7566	0.0000	0.0000	0.0000	0.0083	0.0023	0.0058	0.0032	0.0000	0.0000	0.0015	0.0000
Quarrying & Construction	1.3388	9.8182	1.4201	0.1954	0.4531	0.8437	1.9521	3.3584	4.8269	0.0881	1.9148	0.3389	0.9028	0.4106	0.9534	0.0684	0.6206	0.4703	0.0951	0.0027
Manufacturing	0.3117	1.5380	1.4286	0.1232	0.0386	0.1631	0.8614	1.8421	3.2166	0.1960	0.0239	0.2672	1.4390	0.2510	5.0496	0.0959	1.1197	0.4795	0.8458	0.1676
Electricity	1.3737	0.8180	2.3292	0.0000	0.5441	0.0524	0.3457	5.4093	4.3874	0.0858	2.3840	0.0903	0.2722	0.0782	0.5324	0.0952	0.4391	0.3772	0.2916	0.1588
Water	0.3095	0.0244	0.4985	0.2215	0.0000	0.0031	0.0039	0.1557	0.9538	0.0089	0.1573	0.0041	0.0076	0.0128	0.0484	0.0020	0.0266	0.0023	0.0241	0.0140
Gas, Oil & Fuel Distribution	0.5970	0.3445	0.3077	0.0203	0.0078	0.0305	0.0117	0.4610	1.3596	0.0617	0.0939	0.0122	0.0088	0.0040	0.0747	0.0122	0.0248	0.0028	0.0463	0.0747
Jersey Telecommunications	0.2543	1.1775	0.4078	0.2021	0.0421	0.1411	0.0000	3.1457	1.5445	0.1021	0.0653	0.0634	1.0908	0.4076	1.6842	0.2184	0.7944	0.8878	0.8381	0.0687
Wholesale & Retail Trade	2.4446	5.4874	1.7593	0.0410	0.2913	0.0009	5.2100	1.9152	1.8185	0.0000	0.0000	0.0403	0.0094	0.0479	0.0000	0.0000	0.0394	0.0000	0.0499	0.0101
Hotels, Restaurants & Catering	0.0151	0.2862	0.1578	0.0000	0.0000	0.0000	0.0118	0.0307	0.3092	0.0193	0.0092	0.0788	0.1907	0.0327	0.2810	0.0046	0.0000	0.0951	0.0620	0.0032
Land Transport	0.0553	0.2351	0.1440	0.0000	0.0000	0.0000	0.0097	0.0487	0.2846	0.0000	0.0000	0.0031	0.0059	0.0220	0.1714	0.0000	0.0099	0.1850	0.0015	0.0000
Sea & Air Transport and Transport Support	0.0000	0.0785	1.0280	0.0804	0.0000	0.0000	0.0886	1.8968	1.3588	0.0178	0.0152	0.7835	0.3011	0.0183	0.7949	0.0462	0.0749	0.0612	0.0131	0.2112
Jersey Post	0.2014	0.4278	0.3551	0.1423	0.0963	0.1914	0.2233	4.9313	0.5975	1.4088	0.0060	0.0937	1.4543	0.7377	1.7537	0.0368	0.4332	0.1370	0.8259	0.0712
Banks & Building Societies	3.6149	3.7088	1.3111	0.0796	1.8818	0.0827	0.0423	2.5201	22.8779	0.1852	0.0135	0.0206	0.0424	0.1419	3.8839	0.0133	0.2077	0.0485	0.2673	0.3191
Insurance Companies	0.5168	0.7857	0.2971	0.0180	0.1061	0.0000	0.0824	0.9601	1.0082	0.0959	0.0688	0.0000	0.0071	0.0208	0.5024	0.0801	0.5778	0.0486	0.8665	0.1471
Investment Trusts & Fund Managers	0.0173	0.0000	0.7875	0.0000	0.0000	0.0000	0.0000	0.0742	0.0243	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Computer Services	0.0250	0.4580	0.1408	0.0000	0.0000	0.1049	0.4769	1.1768	0.4569	0.0761	0.0031	0.0433	0.4251	0.0317	1.0276	0.0000	0.1470	3.9983	0.6337	0.0000
Legal Activities	1.0439	0.9603	1.3952	0.3206	0.0367	0.0823	0.1898	10.1174	6.3392	0.5671	0.0000	0.0689	3.5516	1.3261	8.3695	0.4077	2.5030	0.4477	2.9989	0.1203
Accountancy	0.2146	0.7378	0.3390	0.0319	0.0194	0.0135	0.0056	1.7031	1.0045	0.1160	0.0000	0.0000	0.3562	0.3984	0.6038	0.0472	0.2585	0.0032	0.7813	0.1984
Other Business Activities	7.9826	4.3771	3.2105	0.1858	1.8679	0.3652	0.4677	18.5342	4.0812	0.7250	0.1935	1.0978	1.5604	1.3679	8.3349	0.5305	1.7380	3.8191	4.3396	0.2489
Other Services Activities	1.8524	1.1406	0.7460	0.0000	0.0248	0.1974	0.0724	3.0338	0.7075	0.2816	0.1517	0.0386	0.0919	0.0167	0.0570	0.0328	0.0399	0.0133	0.1335	0.0250
Recreation, Culture & Sport	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Education	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Health, Social Work & Housing	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Public Services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Public Administration & Defence	0.2368	0.0169	0.1208	0.0927	0.0629	0.0276	0.0283	0.6248	0.1347	0.0302	0.0380	0.0000	0.0581	0.0241	0.0651	0.0198	0.1081	0.0486	0.0000	0.0055
Total Intermediate Demand	22.7746	32.2170	29.1418	1.7529	5.2736	2.2901	10.0225	62.2861	63.7961	4.0456	5.1381	3.0586	11.7813	5.3547	32.1737	1.7138	9.1821	11.1253	13.2157	1.8404
UK Imports	5.1839	18.1977	23.1556	5.0751	1.0899	0.5099	6.7619	10.3643	7.4019	1.7775	9.6916	0.8538	36.4549	2.1248	16.5688	2.7955	0.1092	1.5796	0.7024	0.5973
REU Imports	0.1382	0.4796	4.4474	8.8643	0.0162	0.0001	0.2902	0.3163	1.1563	0.0239	0.0000	0.0022	1.8678	0.0027	2.7194	0.0000	0.0028	0.0017	0.0028	0.0006
ROW Imports	0.0044	1.2804	0.0032	0.0001	0.0005	0.0000	0.0095	13.4878	0.0029	0.0000	0.0000	0.0001	4.7798	0.0001	1.9027	0.0000	0.0006	0.0000	0.0195	0.0000
Income from Employment	25.6898	81.2558	35.8506	13.0184	2.7559	5.1164	11.7208	115.2788	66.1224	6.3570	23.5913	10.3047	176.6314	15.9477	90.0920	6.2475	36.2040	37.3793	48.4191	13.1065
Other Value Added	8.9972	95.2598	7.8405	15.5920	3.3356	1.1288	13.7357	142.6843	82.8822	8.1292	31.8029	4.3134	891.8605	6.5443	155.8919	6.9638	40.0780	34.9288	29.5940	9.8882
Expenditure Taxes	0.0023	0.0087	0.0121	2.5808	0.0005	5.8274	0.0031	7.4263	2.6306	0.0008	0.0042	0.0004	0.0188	0.0009	0.0093	0.0012	0.0000	0.0007	0.0003	0.0003
Subsidies	-5.7322	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total Primary Inputs	33.9816	198.4820	71.3093	44.9307	7.1986	12.5825	32.8212	289.5579	160.1962	16.2883	64.8900	16.4745	1110.4131	24.6205	296.9842	16.0280	76.3945	73.8880	76.7381	23.5926
Total Output (Inputs)	56.7564	228.6690	100.4512	48.6837	12.4722	14.6726	42.8437	351.8439	223.9924	20.3339	70.0281	18.8331	1122.1944	29.9752	299.1579	17.7416	88.5566	85.0133	89.9537	25.4332

Table 5.3 (continued) An Industry By Industry Input-Output Table For Jersey, 1998 (£millions)

Sectors	Recreation, Culture & Sport	Education	Health, Social Work & Housing	Public Services	Public Admin. & Defence	Total Intern. Demand	Household Consumption	Tourism Expenditure	GDP/CF	Jersey G/GFC	Exports UK	Exports REU	Exports ROW	Stocks	Total Final Demand	Gross Output
Agriculture & Fishing	0.8144	0.0124	0.1875	0.0000	0.0007	19.8620	1.6441	0.0157	0.6959	0.0000	31.7199	2.9994	0.0000	0.0194	37.0944	56.7564
Quarrying & Construction	2.0040	3.2888	4.5676	4.1267	1.3036	45.3369	28.1879	0.0000	155.9186	0.0000	0.0000	0.0000	0.0000	-0.7424	183.3621	228.6990
Manufacturing	0.3669	0.0394	1.5184	0.0702	0.0211	21.4944	19.5475	4.7961	0.3582	0.0000	52.0957	1.3535	0.0000	0.8056	78.9568	100.4512
Electricity	0.9537	0.5798	2.1825	0.9299	0.2802	24.7384	21.8182	0.0000	0.2983	0.0000	0.0000	0.0000	0.0000	0.0328	21.9453	46.6837
Water	0.1755	0.2236	0.8694	0.3797	0.1144	4.2406	4.9586	0.0000	2.7879	0.0000	0.0000	0.0000	0.0000	0.4845	8.2312	12.4722
Gas, Oil & Fuel Distribution	0.3386	0.2998	1.1868	0.5213	0.1559	6.0577	8.3671	0.4414	0.0945	0.0000	0.0000	0.0000	0.0000	-0.0882	8.8149	14.8726
Jersey Telecommunications	0.3532	0.3382	1.2901	0.3981	0.0971	16.7103	27.1133	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.2800	26.8333	42.5437
Wholesale & Retail Trade	0.3320	2.8158	7.9263	0.8393	0.1913	30.8680	137.0142	34.5295	34.7278	0.0000	51.1655	1.0091	54.9263	7.8037	321.1759	351.8439
Hotels, Restaurants & Catering	0.0751	0.1070	0.6345	0.0251	0.0147	2.4416	52.2036	148.7107	0.0000	0.0000	17.8483	1.8206	0.9684	0.1810	221.5508	223.9924
Land Transport	0.0212	0.1027	0.3236	0.5838	0.0085	2.1959	2.4116	8.4980	0.0000	0.0000	7.2356	0.0000	0.0000	-0.0071	18.1380	20.3339
Sea & Air Transport and Transport Support	0.0817	0.0592	0.3507	0.0139	0.0081	7.3600	20.3241	0.8305	0.0000	0.0000	38.9822	2.5313	0.0000	0.0000	62.6681	70.0281
Jersey Post	0.2954	0.2118	0.6256	0.2478	0.0604	15.5659	1.5316	0.1911	0.0000	0.0000	0.7858	0.2872	0.1915	0.0000	2.9672	18.5331
Banks & Building Societies	0.2569	0.2248	0.5788	0.0000	0.0166	42.1177	44.4348	0.0000	0.0000	0.0000	500.8216	221.3128	313.7075	0.0000	1080.0767	1122.1944
Insurance Companies	0.0806	0.1874	0.2280	0.0526	0.0000	6.8959	18.4742	0.0000	0.0000	0.0000	1.4128	0.4396	2.9525	0.0000	23.2792	29.9752
Investment Trusts & Fund Managers	0.0000	0.0000	0.0000	0.0000	0.0000	0.9032	0.0000	0.0000	0.0000	0.0000	80.6713	41.6465	195.9369	0.0000	298.2547	299.1579
Computer Services	0.0983	0.1078	0.5131	0.0000	0.0333	9.9860	0.0511	0.0000	1.7172	0.0000	2.9518	2.0531	0.9826	0.0000	7.7658	17.7418
Legal Activities	1.2440	0.0000	2.1755	0.0788	0.0619	44.3844	31.3641	0.0000	0.0000	0.0000	1.9358	7.8723	0.0000	0.0000	41.1721	85.5566
Accountancy	0.0878	0.0741	0.1950	0.0000	0.0083	7.1956	0.8053	0.0000	0.4288	0.0000	24.3527	13.9663	38.2625	0.0000	77.8177	85.0133
Other Business Activities	1.5127	0.6762	3.5687	0.5222	0.1137	69.4112	5.9852	0.0000	0.0000	0.0000	5.8866	2.0898	6.8009	0.0000	20.5425	89.9537
Other Services Activities	0.2396	0.1243	0.1650	0.1798	0.0792	9.2454	15.9805	0.1943	0.0000	0.0000	0.0196	0.0132	0.0000	0.0000	18.1878	25.4332
Recreation, Culture & Sport	0.0881	0.0000	0.0000	0.0000	0.0876	0.1757	27.1041	3.7804	0.0000	3.8438	3.9311	0.0000	3.9311	0.0000	42.5906	42.7662
Education	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	22.0818	0.0000	0.0000	37.9928	0.0000	1.4426	0.0759	0.0000	61.5930	61.5930
Health, Social Work & Housing	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	80.2415	0.4301	0.0000	77.5597	0.0000	0.0000	0.0000	0.0000	158.2313	158.2313
Public Services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1252	0.0000	0.0000	26.4534	0.0000	0.0000	0.0000	0.0000	26.5785	26.5785
Public Administration & Defence	0.1075	0.0477	0.9157	0.0880	0.0043	2.8822	5.9084	0.0000	0.0000	48.2581	0.0000	0.0000	0.0000	0.0000	54.1675	57.0496
Total Intermediate Demand	9.5262	9.3004	29.9808	8.8368	2.8609	388.4893	577.4372	202.4179	197.0230	194.1076	801.5945	300.6397	618.5582	8.2096	2899.9857	3288.4549
UK Imports	5.3830	4.4044	9.3982	4.3845	9.5909	184.1564	447.2395	34.3753	196.1679	0.0000	0.0000	0.0000	0.0000	0.0000	877.7827	861.9391
REU Imports	0.7193	0.8041	0.1327	0.2172	0.4080	22.4114	24.2557	1.8199	21.2252	0.0000	0.0000	0.0000	0.0000	0.0000	47.4008	69.8122
ROW Imports	0.0006	1.5080	0.0043	0.0071	0.0133	23.0249	0.7915	0.0626	34.5521	0.0000	0.0000	0.0000	0.0000	0.0000	38.4062	58.4311
Income from Employment	15.3540	41.6447	79.2821	13.1310	44.3721	1011.8731	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1011.8731
Other Value Added	11.7805	3.9285	39.4291	0.0000	0.0000	1645.7072	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1645.7072
Expenditure Taxes	0.0027	0.0029	0.0042	0.0020	0.0044	18.5449	9.4785	0.5715	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10.0500	28.5949
Subsidies	0.0000	0.0000	0.0000	0.0000	0.0000	-5.7322	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-5.7322
Total Primary Inputs	33.2401	52.2926	128.2805	17.7417	54.3887	2899.9857	481.7651	36.9294	251.9452	0.0000	0.0000	0.0000	0.0000	0.0000	770.6397	3670.6254
Total Output (Inputs)	42.7662	61.5930	158.2313	26.5785	57.0496	3288.4549	1059.2023	239.3473	448.9682	194.1076	801.5945	300.6397	618.5582	8.2096	3670.6254	6959.0803

Table 5.4 Consumer Expenditure (£million) Broken Down By Household Income Quintiles - Jersey, 1998

Sectors	Household Consumption 1	Household Consumption 2	Household Consumption 3	Household Consumption 4	Household Consumption 5
Agriculture & Fishing	0.1453	0.2481	0.2661	0.2961	0.6885
Quarrying & Construction	1.2060	2.6455	3.8849	7.7099	12.7417
Manufacturing	2.1236	2.5794	4.6086	4.2847	5.9512
Electricity	3.1309	4.0722	4.3984	4.6659	5.3487
Water	0.6897	0.9112	0.9785	1.1031	1.2764
Gas, Oil & Fuel Distribution	0.6988	1.2721	1.5274	2.1472	2.7216
Jersey Telecommunications	2.2930	4.1642	5.5754	6.0542	9.0264
Wholesale & Retail Trade	11.8470	19.0319	25.2532	33.4221	47.4600
Hotels, Restaurants & Catering	2.2995	5.6563	10.0085	11.8923	22.3470
Land Transport	0.1366	0.1866	0.6794	0.5701	0.8389
Sea & Air Transport and Transport Support	1.2432	2.0647	5.1272	4.5278	7.3611
Post	0.1876	0.2006	0.2253	0.5192	0.3990
Banks & Building Societies	0.3521	1.7783	5.5046	14.7034	22.0965
Insurance Companies	1.2462	2.1171	3.3725	3.8750	7.8634
Investment Trusts & Fund Managers	0.0000	0.0000	0.0000	0.0000	0.0000
Computer Services	0.0039	0.0068	0.0094	0.0125	0.0185
Legal Activities	0.3518	1.4695	1.4990	17.3986	10.6451
Accountancy	0.0090	0.0377	0.0385	0.4467	0.2733
Other Business Activities	0.0669	0.2795	0.2851	3.3091	2.0246
Other Services Activities	1.0552	2.6713	3.0303	3.6141	5.5896
Recreation, Culture & Sport	1.8859	3.4850	4.6364	6.2496	10.8473
Education	0.2952	0.8364	1.9378	6.3247	12.6877
Health, Social Work & Housing	8.1019	13.1333	19.1536	16.0423	23.8105
Public Services	0.0073	0.0131	0.0307	0.0105	0.0635
Public Administration & Defence	0.8639	0.9919	1.1096	1.2929	1.6512

Total Intermediate Demand	40.2406	69.8526	103.1404	150.4718	213.7317

UK Imports	36.8697	65.5413	83.1036	107.2379	154.4870
REU Imports	2.0074	3.5234	4.5017	5.8190	8.4041
ROW Imports	0.0655	0.1150	0.1469	0.1899	0.2742
Income from Employment	0.0000	0.0000	0.0000	0.0000	0.0000
Over Value Added	0.0000	0.0000	0.0000	0.0000	0.0000
Expenditure Taxes	0.7816	1.3884	1.7611	2.2728	3.2746
Subsidies	0.0000	0.0000	0.0000	0.0000	0.0000

Total Primary Inputs	39.7242	70.5681	89.5134	115.5195	166.4399

Gross Consumer Expenditure	79.9648	140.4207	192.6538	265.9913	380.1717

3.3 The Jersey IO Table For 1998

I present the final balanced version of the Jersey IO table for 1998 in Table 5.3. This is the table that has been presented to and accepted by the States of Jersey as the IO accounts for 1998, with minor modifications to reflect better data on energy (fuel) use within the energy supply sectors themselves. (These data were only made available by the energy supply firms after the official table was presented). All entries are reported in units of £1million, and the price valuation of all goods is that of producer prices¹¹.

3.3.1 Interpreting The IO Table

We have constructed the Jersey IO table in a “domestic flows/import row” format. Accordingly Table 5.3 should be interpreted as follows:

- Reading along a row, each cell entry shows the sales by the sector on the left to the Jersey sector or market at the top
- Reading down a column, each cell entry shows the purchases by the Jersey sector/market at the top from the sector on the left
- At the bottom of each column are the entries for other value added and the total value of imports of goods and services, income from employment and expenditure taxes and subsidies associated with the sector at the top

¹¹ Producer prices are sellers’ or factory-gate prices plus the costs of transport included in delivering goods to their first destination outside the factory, provided that the cost of transport is not charged for separately. This basis of reporting is chosen mainly because it ensures that bought-in transport and distribution activity is concentrated in the rows and columns of these sectors rather than distributed throughout the table as part of purchasers’ prices. Where commodities are produced elsewhere and solely distributed by a production sector (e.g. ‘Wholesale & Retail Trade’), the distribution margin is recorded as the local sector’s output with the remainder allocated to imports (see Table 5.2).

Note that Table 5.3 only has a single 'Household Consumption' column: in Section 3.2 I state that data are available to disaggregate this final demand category into five income quintile groups (from the 20% of Jersey households with the lowest total income to the 20% with the highest). Household consumption is disaggregated in this way in Table 5.4, as an extension of Table 5.3 (the five columns in Table 5.4 could just as easily be reported in place of the single household column in Table 5.3)

The key sectoral accounting identity for the IO table is:

Total Gross Output = Total Inputs

And for the table as a whole we have:

Total Final Demand = Total Inputs of Primary Factors

Total Intermediate Output = Total Intermediate Input

3.3.2 Sectoral Detail

In Section 3.2 I explain how the Jersey IO table is constructed with the highest level of sectoral detail that is both feasible and practical. In Chapter 3 I explained how the accommodation of a high level of sectoral detail is one of the key strengths of the IO framework. As well as providing a core part of the economic database required for CGE modelling, the IO table is a very useful accounting tool for descriptive analysis of the structural characteristics of individual sectors. For example, by combining Table 5.3 with the sectorally-disaggregated Jersey employment data reported in Table 5.5, we could examine average sectoral wages, gross output per employee, (other) value-added per employee, local intermediate and imported purchases per employee etc.

Table 5.5 Sectoral Distribution Of Employment In Jersey, 1998

Sector	Total Employment	Sectoral distribution
	FTE	%
Agriculture & fishing	2040	4.3
Quarrying & Construction	4745	10.1
Total Manufacturing	2132	4.5
Electricity	426	0.9
Water	81	0.2
Gas and Oil & Fuel Distribution	241	0.5
Jersey Telecommunications	445	0.9
Wholesale & retail trade	7487	15.9
Hotels, restaurants & catering	6024	12.8
Land transport	410	0.9
Sea & Air Transport & Transport Support	908	1.9
Post	363	0.8
Banks and building societies	5757	12.2
Insurance Companies	429	0.9
Investment Trusts & Fund Managers	1955	4.1
Computer services	354	0.8
Legal Activities	1247	2.6
Accountancy	1174	2.5
Other Business Activities	2176	4.6
Other Service Activities	882	1.9
Recreation, Culture & Sport	888	1.9
Education	1508	3.2
Health, Social Work & Housing	3341	7.1
Public Services	573	1.2
Public Administration and Defence	1525	3.2
Total	47111	100

Source: States of Jersey Manpower Database, 1998,
and Fraser of Allander Institute estimates

In terms of the environmental focus of my dissertation, useful descriptive analysis can be carried out to determine which sectors are the most resource intensive by looking at different types of energy-use and/or water intensity per unit of output or per employee. For example, the Water supply sector has the highest purchases of electricity per unit of output produced, while Public Services is intensive in purchases of all the resources that are likely to have direct environmental impacts in Jersey (water, electricity and gas and fuels), as is Agriculture & Fishing.

However, these monetary measures are unlikely to reflect the actual relative resource intensity of different sectors as unit costs vary across sectors for some resource inputs. Moreover, as I go on to explain in Chapter 6, the output of energy sectors such as 'Oil & Fuel Distribution' sector is actually composed of several different types of fuel (with different unit cost and pollution properties). Therefore, when considering energy intensity, for example, it is better to use the *physical* fuel use data reported in Table 6.1 of Chapter 6. Similarly, the pollution impact of energy use can be more fully examined using the environmentally augmented IO system that I construct in Chapters 6 and 7.

Note, however, that the version of the Jersey IO table reported in Table 5.3 only has 25 production sectors compared to the 28 sectors identified in Table 5.1: we have aggregated six sectors from the 28-sector version into 3 new sectors. These are Quarrying & Construction, Gas, Oil & Fuel Distribution and Investment Trusts & Fund Managers.

In the case of Quarrying & Construction and Gas, Oil & Fuel Distribution, our decision to aggregate these particular sectors is based on disclosure restrictions. We made a promise to all respondents participating in the industrial survey that any information relating to their firm would not be disclosed to anyone outside the Fraser of Allander Institute. Moreover, respondents were assured that it would not be possible to trace firm-specific information from the IO table presented to the States of Jersey. However, given that there are only eight quarrying firms operating in Jersey, one gas and three fuel

distribution firms, clearly there is a risk then that commercially sensitive information could be extracted from the 28-sector IO table, particularly in the case of the gas sector. (Electricity and Water are also single-firm sectors: however these are part-publicly owned and are required to make their accounts available to the States of Jersey in any case.)

In terms of the environmental focus of my thesis, the need to aggregate the Gas sector with Oil & Fuel Distribution may appear to be the biggest problem arising from the disclosure restrictions. However, because more detailed energy supply and consumption data are available to me it is in fact possible to model energy-related problems with these two sectors separately identified for a more detailed breakdown of physical fuel use, even if there are constraints on how these are reported.

In the case of Investment Trusts & Fund Managers we aggregate the two sectors that are separately identified in the 28-sector version mainly for practical reasons. In this case the combination is not fixed by confidentiality constraints. These sectors are combined simply because the initial version of the CGE modelling programme used here has only been fully tested for the 25-sector case and, due to the low level of integration into the local economy of both individual sectors, they seem natural candidates for aggregation.

At this stage, with the IO table and sectoral employment data reported in Tables 5.3 – 5.5, it would be possible for me to proceed to specification and calibration of the most straightforward type of general equilibrium model, a standard IO model of the Jersey economy. However, I postpone this development until after I report the construction of the environmental database in Chapter 6, instead specifying and calibrating an economic-environmental IO model of Jersey in Chapter 7. My objective, though, is to develop a more flexible CGE modelling framework (which encompasses IO as a limiting case). Therefore, it is necessary to augment the IO database with information on income flows, to allow us to generate a SAM for Jersey, investment demands and the supply-side of the labour market.

4. Construction Of The Jersey SAM For 1998

In national accounting terms, what the IO table tells us is how income is generated within the target economy during the time period in question – i.e. it tells us about the composition of the economy's gross domestic product (GDP) by describing the structure of production. What the IO table does not tell us, however, is how this income is distributed among the main transactors who engage in economic activity in the target economy. For example, the IO table does not tell us how much of the income generated within the local economy actually accrues to the people who live within its boundaries and how much flows to external transactors. Nor does it tell us how much income residents of the local economy earn as a result of income generation that takes place elsewhere. These are extremely important issues, both in terms of national accounting (gross national product, GNP, the total income actually accruing to local residents, is generally thought to be a better indicator of welfare than GDP) and in terms of modelling the impacts of disturbances to the target economy.

Moreover, as well as production, the IO table tells us about the consumption/expenditure patterns of the different types of transactor. However, it does not tell us much about the income side of the equation. For example, in the case of households, the IO table only tells us about wage income, which, certainly in the case of Jersey, is not sufficient to finance total household expenditure. Where does the additional income required to fund consumption come from? Is it generated from some local source not reported in the IO, or abroad? How much is saved and invested? If we want to properly model and analyse behaviour in the economy, we must incorporate more comprehensive information on income and expenditure flows in the database that provides the statement of initial equilibrium conditions. The framework that fulfils this requirement is a social accounting matrix (SAM).

4.1 SAM Structure And Additional Data Requirements

4.1.1 Structure Of The Jersey SAM

Figure 5.2 Schematic Structure Of The Basic SAM For Jersey, 1998

Expenditure by Income to	Production Activities (the I production sectors)	Institutions H C G CF E	Factors of Production Labour (L) Capital (K)
Production Activities	T	U	
Institutions: H C G CF E	V	W	X
Factors of Production : L (Value Added) K	Y		

The SAM framework is similar to a set of an IO accounts: as in the IO table, row entries in a SAM record incomes/receipts and column entries record expenditures/outlays. They are both examples of single entry book keeping, with every entry appearing in both a row and column (i.e. each item of income to one transactor must be an item of expenditure by another so that total receipts equal total outlays). However, unlike an IO table, a SAM does not just record income from and expenditure on the sale and purchase of goods and services. A SAM also records transfers of income (such as flows of profits

to and from the operators to the owners of capital and other property, income taxes, social security payments etc) between the five main aggregate transactors/institutions:

1. Households (**H**)
2. Corporate (all private firms) (**C**)
3. Government (as a producer and final demander) (**G**)
4. Capital Formation (**CF**)
5. External (UK, REU and ROW and tourists) (**E**)

In Figure 5.2 (above) I provide a schematic representation of the basic SAM framework that is used in this section as a template for constructing the Jersey SAM for 1998.

Explanation of each of the elements in Figure 5.2:

The bold capital letters in each of the blocked areas in Figure 5.2 represent a sub-matrix of cells showing, along the rows, the value of the income flow to the transactor identified down the left-hand side of the SAM from the transactor identified along the top of the SAM. Where no letter is shown in a block, this means that no interaction takes place: e.g. none of the production sectors receive income from either of the factors of production. Where the letter is shown in standard bold format, this means that data can be taken directly from the IO table; where the letter is shown in bold italic, this means additional data are required for construction of the SAM. Production sectors are identified by the subscript i (where $i = 1, \dots, I$), institutions/aggregate transactor groups by a (where $a = 1, \dots, A$), and factors of production by b (where $b = 1, \dots, B$). Therefore

- T is an $I \times I$ matrix of intersectoral transactions between the I production sectors of the economy
 - Sub-matrix T is identical to Quadrant 1 of the IO table (see Figure 5.1).
- U is an $I \times A$ matrix of final demand expenditures by the A institutional transactors identified above on the outputs of the I local production sectors.

- The entries for sub-matrix U are given by the final demand block (Quadrant 3) of the IO table (the aggregate transactor 'Corporate' is not a final demander so all the column entries for C in matrix U are equal to zero).
- V is an $A \times I$ matrix of income flows from the I production sectors to the A institutional transactors.
 - In the Jersey SAM the only positive elements of sub-matrix V are payments from production sectors to the three non-tourist external (E) transactors in the form of purchases of imports (taken from Quadrant 2 of the IO table) and net commodity taxes paid to Government (G).
- W is an $A \times A$ matrix of income transfers between the A institutional transactors.
 - Data can be taken from the IO table on import purchases from the External sector by each of the institutional transactors (except 'Corporate', where import purchases are already recorded for each individual production sector in V) and net commodity taxes paid to Government (again, with the exception of 'Corporate'). Data requirements for the remaining elements of sub-matrix W are additional to the SAM – these are detailed individually in Section 4.2 below.
- X is an $A \times B$ matrix of factor income payments to each of the aggregate transactors based on factor services supplied.
 - The total factor income payments are the totals of the 'other value-added' and 'income from employment' rows of the IO table. Since Jersey households provide all labour services to production, payments from Labour (L) to Households (H) are the entry in the (L) column of sub-matrix X . 'Other value-added' (payments to capital) are allocated based on the ownership of firms by the three aggregate transactors, Households, Government and Corporate. Shares of 'other value-added' accruing to foreign owners are transferred from Corporate to External in sub-matrix W .
- Y is a $B \times I$ matrix of payments to value-added/factors of production by each of the I production sectors.
 - Sub-matrix Y is identical to the 'income from employment' and 'other value-added' rows of Quadrant 2 of the IO table.

4.1.2 Balancing Identities

The balancing requirement of the SAM is that for each individual production sector, i , for each institutional/aggregate transactor, a , and for each factor of production, b , the following identity must hold:

$$\text{Total income (receipts)} = \text{total expenditure (outlays)}$$

Note that the SAM need not be a square matrix: one individual transactor's expenditures may be recorded using more than one column and its incomes may be recorded using more than one row. For example, in the Jersey SAM the expenditures of the aggregate External transactor (E) are recorded in four columns showing exports to each of the three geographical destinations, UK, REU and ROW, and to tourists (the only export group that consumes within the Jersey economy). Similarly while Government expenditures are recorded in a single column, Government income is recorded in three rows in order to separately identify revenue from net commodity taxes (divided into negative income from subsidy payments and expenditure taxes) and all other incomes.

My main motivation for splitting some categories of income and expenditure in this way for the Jersey SAM is related to the database requirements of the CGE modelling framework that I use as a template in this project (see Chapter 8). This framework requires that I separately identify exports to and imports from different geographical destinations and production subsidies, for example, as distinct variables in the model dataset.

4.2 SAM Data Collection And Organisation – Construction Of A Set Of Income-Expenditure Accounts For Jersey, 1998

The additional data requirements for the SAM are mainly concentrated in sub-matrix W : transfers of income between the 5 main transactors – Corporate, Government,

Households, Capital Formation and External. The only other additional piece of information that I require is the shares of other value added going to the local producer groups of corporate (privately operated firms), government (publicly operated firms) and households (firms operated solely by self-employed owners) – i.e. sub-matrix *X*. Since all the entries that require additional data to that provided by the IO table are contained within the rows and columns of the five aggregate/institutional transactors, it is possible to deal with all these data gaps by constructing a set of **income-expenditure accounts** for each transactor.

In this section I construct the income-expenditure accounts for Jersey in 1998 in such a way that these are sufficient to meet all additional data requirements for construction of the SAM. I achieve this by ensuring that each missing entry in the framework illustrated in Figure 5.2 is included as an item in the appropriate account(s). Moreover, completion of a set of internally consistent income-expenditure accounts means that I also automatically balance the SAM. In Section 3.2 I explained that a non-manual balancing programme is employed to finally balance the IO table as a whole; however in the case of the SAM, balancing is constrained by the fixed IO entries. Therefore it is necessary for me to manually balance the Jersey SAM on the basis of the additional entries in the income-expenditure accounts alone. However, as I have noted above (in Section 4.1) one of the key characteristics of a SAM is that it is an example of single entry bookkeeping – i.e. any item of expenditure in one account (a column entry) must appear as an item of income in another (a row entry). By constructing the five sets of income-expenditure accounts observing this rule it is possible to fulfil all the additional data requirements and automatically manually balance the SAM.

In constructing the income-expenditure accounts for the Jersey SAM, I begin with the three local transactors – corporate, government and households – for which data are more readily available from existing surveys and the States of Jersey. Figure 5.3 shows the common format that I use for all three of these accounts. The actual income-expenditure accounts used for the 1998 Jersey SAM are recreated in Table 5.6.

Figure 5.3 Template For Constructing Income-Expenditure Accounts

<i>Income</i>	<i>Expenditure</i>
Income from employment (H)*	IO final demand expenditure
Income from OVA*	(incl expend taxes)*
Net commodity taxes (G)*	
Payments from corporations**	Payments to corporations **
Payments from government**	Payments to government**
Payments from households**	Payments to households**
Transfers from UK**	Transfers to UK**
Transfers from REU**	Transfers to REU**
Transfers from ROW**	Transfers to ROW**
	Payments to capital (savings)***
<i>Notes:</i>	
1. Items marked * are fixed by the balanced IO table (using a share parameter in the case of income from OVA)	
2. Items marked ** are constrained only by the corresponding entry in another account – e.g. payments to corporations in the household account must correspond to payments from households in the corporate account	
3. Items marked *** are balancing entries which ensure that income = expenditure	

Table 5.6 Income-Expenditure Accounts - Jersey 1998 (£million)

<u>Government Account</u>			
Income	448.3	Expenditure	448.3
Income from OVA	91.6	IO final demand expenditure	227.8
Net commodity taxes	22.9	Payments to corporations	58.2
Income from households	164.0	Payments to households	102.1
Income from corporations	169.8	Transfers to UK	0.9
		Payments to capital (savings)	59.3
<u>Corporate Account</u>			
Income	1650.2	Expenditure	1650.2
Income from OVA	1573.6	Payments to households	272.2
Income from households	12.4	Payments to government	169.8
Income from government	58.2	Transfers to UK	802.6
Income from UK	5.7	Transfers to REU	107.0
Income from REU	0.0	Transfers to ROW	160.5
Income from ROW	0.4	Payments to capital (savings)	138.1
<u>Household Account</u>			
Income	1563.4	Expenditure	1563.4
Income from employment	1011.9	IO expenditure	1059.2
Income from OVA	14.2	Payments to corporations	12.4
Income from corporations	272.2	Payments to government	164.0
Income from government	102.1	Payments to capital (savings)	327.8
Income from UK	130.4		
Income from REU	16.3		
Income from ROW	16.3		
<u>External Account</u>			
UK income from Jersey	1665.5	UK expenditure in Jersey	937.7
Goods & Services	861.9	Goods & Services	801.6
Transfers	803.5	Transfers	136.1
REU income from Jersey	176.8	REU expenditure in Jersey	316.9
Goods & Services	69.8	Goods & Services	300.6
Transfers	107.0	Transfers	16.3
ROW income from Jersey	219.0	ROW expenditure in Jersey	635.3
Goods & Services	58.4	Goods & Services	618.6
Transfers	160.5	Transfers	16.7
		Tourist expenditure in Jersey	239.3
Total income	2061.3	Total expenditure	2129.2
		Trade balance with Jersey	-68.0
<u>Capital Account</u>			
Income	457.2	Expenditure	457.2
Payments by households	327.8	GDFCF	449.0
Payments by government	138.1	Stocks	8.2
Payments by corporate	59.3		
UK transfers	616.5		
REU transfers	-182.0		
ROW transfers	-502.5		

4.2.1 The Government Account

I construct the Jersey government account first, because this is the one for which information is most readily available and for which the definition and size of entries can be most easily confirmed. The fixed IO entries here are final demand expenditure by government (which I take from the General Government Final Consumption, GGFC, column in the IO table, Table 5.3) and net commodity tax income (the expenditure tax row minus subsidies). I take income from other value-added (OVA) to be the OVA from the 4 public sectors ('Education', 'Health, Social Work & Housing', 'Public Services' and 'Public Administration') in the IO table plus a share of 'Recreation, Culture & Sport' OVA which corresponds to the share of public ownership in this sector (0.16). The Jersey Government also earns trading profits from harbour, airport, telecommunications and postal activities although the sectors that these activities belong to are mainly privately owned and operated. The amount earned by this method in 1998 is recorded in the public sector accounts and is recorded as a transfer from the corporate to government account.

Government to government payments are by definition zero (the receipt of an intra-governmental transfer by one department is offset by a corresponding expenditure in another). This leaves the following items to be determined (see Table 5.6 for numerical results):

Government income:

- **Payments from corporations.** On the basis of consultation with the States of Jersey, I take this entry to consist of corporate income tax payments made in 1998, along with rent payments on government-owned property and interest payments from local banks on government-held accounts.

- **Payments from households.** Again, after checking with the States of Jersey, I take this entry to be equal to income tax and social security fund contributions paid by households in 1998, along with rent payments by households on government-owned housing stocks. The States of Jersey have provided figures on all these items.
- **Transfers from the external sector.** The remaining income items will be any transfers to the States of Jersey from any of the three international transactors. However the States of Jersey report no such recorded income and therefore I assume these to be zero entries.

Government expenditure:

- **Payments to corporations.** I assume these to be grants and subsidies (net of the production subsidies recorded in the IO table). Data on aggregate payments of this kind are given in the States of Jersey public sector accounts. However this is the item that I am least confident about in the government account as I have encountered problems in identifying the various types of subsidies paid by different government departments. Therefore I use additional information provided by firms during the industrial survey process to supplement the information in the public sector accounts. Ultimately, though, I use this as the balancing entry in the government account because good information is available on savings by the States of Jersey (savings are commonly taken to be the balancing entry in an income-expenditure account).
- **Payments to households.** I take these to be social security payments along with grants and subsidies. Again, the States of Jersey have provided figures on these items for 1998.

- **Payments to the external sector.** There is only one recorded transfer from the States of Jersey to an external transactor in 1998: the contribution paid to the UK for defence.
- **Government savings.** As I note above, savings are commonly used as the balancing item in an income-expenditure account. However, the Jersey public sector accounts give firm figures on the amount saved by different methods in 1998. Therefore I can satisfactorily quantify this entry, allowing balancing to focus on the government payments to corporate entry that I am less confident about.

4.2.2 The Corporate Account

In the corporate account the IO items ‘income from employment’ and ‘final demand expenditure’ are not relevant: wages are an outlay by individual firms in each of the production sectors – recorded in sub-matrix **Y** of the SAM – and firms only have intermediate demand for locally produced output. I take income from other value-added (OVA) to be all OVA from the IO tables that is not allocated to government (publicly owned or operated activities) or households (production activities by self-employed persons with no employees or partners) – the household account is discussed below.

As I explain above for the government to government entry, payments from corporations to other corporations will by definition be equal to zero in the aggregate corporation account. (This entry records the transfer of income between firms operating locally, and such an income for one firm will be offset by a corresponding outlay by another firm.) This leaves the following items to be determined (see Table 5.6 for numerical results):

Corporate income:

- **Payments from government.** This entry consists of the grants and subsidies recorded as the corresponding expenditure item in the government account (see above).
- **Payments from households.** I determine these using additional information gathered during the industrial survey process carried out for the construction of the IO table. In the survey questionnaires (see Appendix 5A) firms are asked for information on transfer payments from other local firms, households, government, and abroad in the form of rents, interest payments or any other miscellaneous payments. Responses are grossed-up in the manner described in Section 3.2 and this determines payments by households to government.
- **Transfers from the external sector.** As with payments from households, I determine payments to corporate from each of the three external transactors using the additional survey data gathered during the IO survey process.

Corporate expenditure:

- **Payments to government.** As I explain above for the income side of the government accounts, I take corporate payments to government to be corporate income tax payments in 1998.
- **Payments to households.** Information regarding payments to households by local firms are included in the additional (grossed-up) survey data used to determine income entries on the corporate account. However, the Jersey Tax Office has provided me with data on household income from local firms in the form of private pension income, bank interest and dividends. I judge the tax office data to be more reliable than the survey estimates (which are incomplete for this item), although the two figures are found to be relatively close. The only piece of information that I take from the industrial survey data for this entry is rent payments to households by firms.

The tax office could only provide a figure for aggregate rent income received by local households, which does not identify how much came from commercial or residential sources.

- **Payments to the external sector.** Information on transfers of income from Jersey firms to external transactors is the most problematic entry in the corporate account and for the SAM in general. However, this is likely to be a very important item in the case of Jersey since there is a high level of foreign ownership, particularly in the largest sector, 'Banks & Building Societies'. Unfortunately, the firms surveyed proved reluctant to provide data on this item. Moreover, firms operating in Jersey are not obliged to make information on ownership and/or the amount of income remitted to foreign owners known to the States of Jersey. Therefore I take what I judge to be the best alternative course of action. First I have to estimate the share of foreign-ownership in each sector by each external transactor. I do this by going through the list of Jersey firms recorded in the States of Jersey's Manpower Database (which has 100% coverage of firms operating on the Island), identifying foreign-owned firms on the basis of factors such as head office addresses. Then I apply my estimate of the share of foreign ownership in each sector to the total OVA entry from the IO table to estimate the share of profit income that is earned by external transactors.
- **Payments to capital.** I take savings as the balancing item in the corporate account. However, given the problems I have explained above with respect to determining important entries in the corporate account, this item is highlighted as being open to possible amendment when it comes to final balancing of the SAM. Nonetheless, I note that at just under 10% of total corporate income, the corporate savings estimate recorded in Table 5.6 is not out of line with those of comparable economies, and was consistent with what was required to balance the capital account (see below).

4.2.3 The Household Account¹²

The fixed IO entries in the household income-expenditure account are income from employment and final demand expenditure by households. As I note above, I take the share of total OVA accruing to households to be payments to OVA in firms that are owned and operated by self-employed persons with no employees or partners. I estimate this entry by going through the States of Jersey Manpower Database identifying the share of firms with one or less employees in each sector and applying this to the corresponding sector's OVA entry in the IO table.

With the household to household entry being by definition equal to zero, the remaining items in the household account are (see Table 5.6 for numerical results):

Household income:

- **Payments from corporations.** This item is already identified and discussed in terms of the corresponding entry in the corporate account. There I explain that I use Jersey Tax Office data for household income from local bank deposit interest, dividends from local firms and private pension income, and industrial survey data for rent income from local business to determine this item.
- **Payments from government.** This item is also already identified and discussed, this time in terms of the corresponding entry in the government account, consisting of social security benefits (including States pension income) and grants and subsidies.

¹² At this time I have only been able to identify entries for an aggregate household income-expenditure account. Therefore, I could not construct a SAM where households are disaggregated into the five income groups identified in the IO table. The implication of this is that while IO modelling is possible using disaggregated households, I am unable to extend this to the more flexible CGE framework.

- **Payments from the external sector.** The entries for household income from UK, REU and ROW are determined using Jersey Tax Office data on household income earned abroad from private pensions and other non-wage income (such as investments and property income).

Household expenditure:

- **Payments to corporations.** Again, this item is identified and discussed above with respect to the corresponding entry in the corporate account, where I explain that these payments are determined from industrial survey data on rent, interest and other payments received from households.
- **Payments to government.** Also identified above for the corresponding income entry in the government account, where I explain that this item is taken to be income tax payments, social security contributions and rent payments on government housing stock.
- **Payments to the external sector.** I am currently unable to find any data on transfers from Jersey households to external transactors. For now I take this to be a zero entry. However, both the private and public sectors make significant use of migrant labour on the basis of short-term contracts. Therefore, I would expect that a share of income from employment in Jersey would actually be repatriated in the form of foreign workers sending or taking money earned in Jersey back to the country where they have permanent residence. At this time I am unable to make any kind of estimate because data are not available on the structure of employment in each sector in terms of whether workers have foreign or local residency status or on the duration of their stay in Jersey. However, I hope to be able to be able to estimate this for future versions of the Jersey SAM, when and if appropriate data become available (for example, from the census carried out in Jersey in 2001).

- **Payments to capital.** I take savings to be the balancing item in the household account. The resulting entry shown in Table 5.6 equates to a savings rate of around 21% of total household income. This appears to be a high savings rate relative to the average in economies like the UK. However, there are a lot of high-income households in Jersey, who (according to Jersey household income and expenditure survey data) appear to account for the majority of savings on the Island. I have consulted with the statisticians in the States of Jersey who are responsible for the household income and expenditure survey and on this basis the figure reported in Table 5.6 is judged to be acceptable until such a time as better data become available.

4.2.4 The External Account

Income from the sale of goods and services in Jersey by each of the external transactors are given by the import rows in the IO table. Similarly, the exports and tourist expenditure columns in the IO table give expenditure on Jersey goods and services by each external transactor¹³. The additional items that I need to account for in the SAM are transfers of income in both directions between firms operating in Jersey, local households and government and each external transactor. However these are all accounted for in the government, corporate and household accounts above.

The only remaining item, then, is savings by external transactors in Jersey in terms of the trade balance: if the income earned by an external transactor in Jersey exceeds its expenditure (i.e. it runs a trade *surplus* with Jersey) this amounts to positive savings by the transactor on the Island. Conversely if an external transactor spends more than it earns in Jersey (i.e. it runs a trade *deficit* with Jersey) this amounts to negative saving, or borrowing by the transactor in the Jersey economy. The external income-expenditure account in Table 5.6 shows the aggregate balance for *all* transactors with Jersey. This is

a negative number, showing that the rest of the world as a whole runs a trade deficit with Jersey and effectively borrows rather than saves in Jersey. However Jersey does not run a surplus in its interactions with all external transactors. From Table 5.6 note that the value of the entries income earned in Jersey by the UK – i.e. revenue from UK goods and services sold in Jersey and transfers from Jersey firms and government – exceeds the value of the corresponding expenditure items. I disaggregate Jersey's trade surplus to reflect this in detailing the impact of external transactors on the capital account.

4.2.5 The Capital Account

Receipts to the capital account consist of savings from all the other accounts, and outlays are gross domestic fixed capital formation (the supply of investment goods) and stock building. The latter are already determined in the IO table – the two capital formation columns in the SAM have identical entries to the GDFCF and 'stocks' columns in Table 5.3 - meaning that the additional information required in the SAM is the pattern of savings that fund this capital formation.

I already have this information from constructing the other accounts above. The savings for entry in the expenditure account for each transactor is shown in the 'income' column of the capital account in Table 5.6. Note that the total savings by the three local aggregate transactors – households, government and corporate – exceed the level of capital formation in Jersey. This is what allows Jersey to effectively 'lend' to the rest of the world via its trade surplus. However, in the capital account I break down the impact of the different external transactors on the Jersey capital account according to the three geographical areas UK, REU and ROW.¹⁴ The result is that the capital account shows the UK as a net saver in the Jersey economy, while REU and ROW are net borrowers.

¹³ The tourist expenditure column also includes imports from UK, REU and ROW that are consumed by tourists in Jersey; however this is automatically cancelled out by taking the import row totals as income earned by external transactors.

¹⁴ Note that the IO table does not disaggregate tourist expenditure by the geographical residence of visitors to the Island. In allocating the deficit, I assume that share of tourist demand from each of the three regions, UK, REU and ROW, is the same as what applies for general export demand.

Table 5.7 Jersey SAM 1998 (£million)

		IO data		S&M data		Adj. IO totals		Production Activities																																	
		Sector/Transaction		Agriculture		Quarrying & Construction		Manufacturing		Electricity		Water		Gas, Oil & Fuel		Jewelry		Wholesale & Retail Trade		Hotels, Rest.		Land Transport		Sea & Air Transp.		Finance		Banks & Building Soc.		Insurance		Inv. Transf. & Services		Computer		Legal		Ammunition		Other Bus. Activities	
		# Flt/ing		Construction		Manufacturing		Electricity		Water		Fuel Del.		Telecomm.		Retail Trade		# Catering		Transport		# Trans. Sapp.		Post		Building Soc.		Companies		Fund Mgmt.		Services		Activities		Ammunition		Activities			
P		Agriculture & Fishing		0.6		0.0		11.0		0.0		0.0		0.0		0.0		0.3		6.8		0.0		0.0		0.0		0.0		0.0		1.0		0.1		0.5		0.1			
R		Quarrying & Construction		1.3		9.8		1.4		0.2		0.5		0.8		2.0		3.4		4.8		0.1		1.9		0.3		0.9		0.4		1.0		0.1		0.5		0.1			
O		Total Manufacturing		0.3		1.5		1.4		0.1		0.0		0.2		0.9		1.8		3.2		0.2		0.0		0.3		1.4		0.3		5.0		0.1		1.1		0.5		0.0	
D		Electricity		1.4		0.6		2.3		0.0		0.5		0.1		0.3		5.4		4.4		0.1		2.4		0.3		0.1		0.5		0.1		2.4		0.4		0.4		0.3	
U		Water		0.3		0.0		0.5		0.2		0.0		0.0		0.0		0.2		1.0		0.0		0.2		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
C		Gas, Oil & Fuel Distribution		0.6		0.3		0.3		0.0		0.0		0.0		0.0		0.5		1.4		0.1		0.1		0.0		0.0		0.0		0.1		0.0		0.0		0.0		0.0	
T		Jewelry Telecommunications		0.3		1.2		0.4		0.2		0.0		0.1		0.0		3.1		1.5		0.1		0.1		0.1		0.0		1.7		0.2		0.8		0.2		0.9			
I		Wholesale & Retail Trade		2.4		5.5		1.8		0.0		0.3		0.0		5.2		1.9		1.6		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
O		Hotels, Restaurants & Catering		0.0		0.3		0.2		0.0		0.0		0.0		0.0		0.0		0.3		0.0		0.1		0.2		0.0		0.0		0.3		0.0		0.0		0.1		0.1	
N		Land Transport		0.1		0.2		0.1		0.0		0.0		0.0		0.0		0.0		0.3		0.0		0.0		0.0		0.0		0.0		0.2		0.0		0.0		0.2		0.0	
A		Sea & Air Transport & Transport Support		0.0		0.1		1.0		0.1		0.0		0.1		1.9		1.4		0.0		0.0		0.0		0.3		0.0		0.0		0.0		0.1		0.1		0.1		0.0	
C		Post		0.2		0.4		0.4		0.1		0.1		0.2		4.9		0.6		1.4		0.0		0.1		1.5		0.7		1.8		0.0		0.4		0.1		0.1		0.0	
T		Banks & Holding Societies		3.6		3.7		1.3		0.1		1.7		0.1		0.0		2.5		22.9		0.2		0.0		0.0		0.1		3.9		0.0		0.2		0.0		0.0		0.3	
I		Insurance Companies		0.5		0.8		0.3		0.0		0.1		0.0		0.1		1.0		1.0		0.1		0.1		0.0		0.0		0.5		0.1		0.6		0.0		0.0		0.9	
V		Investment Trusts & Fund Managers		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.1		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
I		Computer Services		0.0		0.5		0.1		0.0		0.0		0.1		0.5		1.2		0.5		0.1		0.0		0.0		0.4		0.0		1.0		0.0		0.1		4.0		0.6	
T		Legal Activities		1.0		1.0		1.4		0.3		0.0		0.1		0.2		10.1		6.3		0.6		0.1		0.3		3.6		1.3		0.4		0.4		2.5		0.4		3.0	
I		Accountancy		0.2		0.7		0.3		0.0		0.0		0.0		0.0		1.7		1.0		0.1		0.0		0.0		0.4		0.4		0.6		0.3		0.0		0.0		0.8	
E		Fiber Business Activities		8.0		4.4		3.2		0.2		1.9		0.4		0.5		18.5		4.1		0.7		0.2		1.1		3.6		1.4		6.3		0.5		1.7		3.8		4.3	
S		Other Services Activities		1.7		1.1		0.7		0.0		0.0		0.2		0.1		3.0		0.7		0.3		0.2		0.0		0.1		0.0		0.1		0.0		0.0		0.1		0.1	
		Recreation, Culture & Sport		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
		Education		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
		Health & Social Work & Housing		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
		Public Services		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
		Public Administration & Defense		0.2		0.0		0.1		0.1		0.1		0.0		0.0		0.6		0.1		0.0		0.0		0.1		0.0		0.1		0.0		0.1		0.0		0.0		0.0	
I	(N)	Households		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
N	(C)	Jewelry Corporates		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
S	(N)	Government		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
T		Transp. Expenditures		0.0		0.0		0.0		2.6		0.0		8.8		0.0		7.4		2.6		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
I		Rebates		-5.7		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
U	(C)	Capital		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
T	(E)	R&D		5.2		18.2		23.2		5.1		1.1		0.5		6.8		10.4		7.4		1.8		9.7		0.9		36.5		2.1		16.6		2.8		0.1		1.6		0.7	
I		Goods and Services		5.2		18.2		23.2		5.1		1.1		0.5		6.8		10.4		7.4		1.8		9.7		0.9		36.5		2.1		16.6		2.8		0.1		1.6		0.7	
O		Treasury		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
N		R&D		0.1		0.5		4.4		8.7		0.0		0.0		0.3		0.3		1.2		0.0		0.0		0.0		1.9		0.0		2.7		0.0		0.0		0.0		0.0	
S		Goods and Services		0.1		0.5		4.4		8.7		0.0		0.0		0.3		0.3		1.2		0.0		0.0		0.0		1.9		0.0		2.7		0.0		0.0		0.0		0.0	
		Treasury		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
		R&D		0.0		1.3		0.0		0.0		0.0		0.0		0.0		13.5		0.0		0.0		0.0		4.8		0.0		1.9		0.0		0.0		0.0		0.0		0.0	
		Goods and Services		0.0		1.3		0.0		0.0		0.0		0.0		0.0		13.5		0.0		0.0		0.0		4.8		0.0		1.9		0.0		0.0		0.0		0.0		0.0	
		Treasury		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
Values of	(C)	Business Investment		28.7		81.3		39.9		13.0		2.8		5.1		11.7		115.3		66.1		6.4		23.6		10.3		175.6		15.9		90.1		6.2		36.2		37.4		46.4	
Expenditures	(E)	Other Value Added		8.7		98.3		7.8		15.6		3.3		1.1		13.7		142.7		82.9		8.1		31.6		4.3		891.7		6.8		158.7		7.0		40.1		34.9		29.6	
		Expenditure totals		56.76		228.70		100.45		46.68		12.47		14.87		42.54		351.84		223.99		20.33		70.03		18.53		1122.19		29.98		299.16		17.74		85.56		85.01		89.95	

Table 5.7 (continued) Jersey SAM 1998 (£million)

		IO data						SAM data						Adj. IO totals						
		Production Activities (continued)						Institutions/Aggregate transactors										Factors of Production		
												Capital Formation (CF)		External (E)				Labour (L)		Capital (K)
																		Employment		Other
																		Income		Value Added
																		Totals		
Sectors/transactors		Other Service	Recreation, Cult. & Sport	Education	Health, Social Work & Housing	Public Services	Public Admin. & Defence	Households (H)	Corporate (C)	Government (G)	Gross domestic Band capital formation	Change in stocks	Tourists	RUK	REU	ROW				
Activities																				
P	Agriculture & Fishing	0.0	0.8	0.0	0.2	0.0	0.8	1.6	0.0	0.0	0.7	0.0	0.0	31.7	3.0	0.0	0.0	0.0	56.76	
R	Quarrying & Construction	0.0	2.0	3.3	4.6	4.1	1.3	28.2	0.0	0.0	155.9	-0.7	0.0	0.0	0.0	0.0	0.0	0.0	228.70	
O	Total Manufacturing	0.2	0.4	-0.0	1.5	0.1	0.0	19.3	0.0	0.0	0.4	0.8	4.8	52.1	1.4	0.0	0.0	0.0	100.45	
D	Electricity	0.2	1.0	0.6	2.2	0.9	0.3	21.6	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.68	
U	Water	0.0	0.2	0.2	0.9	0.4	0.1	5.0	0.0	0.0	2.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	12.47	
C	Gas, Oil & Fuel Distribution	0.1	0.3	0.3	1.2	0.5	0.2	8.4	0.0	0.0	0.1	-0.1	0.4	0.0	0.0	0.0	0.0	0.0	14.87	
T	Energy Telecommunications	0.1	0.4	0.3	1.3	0.4	0.1	27.1	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	42.54	
I	Wholesale & Retail Trade	0.0	0.3	2.6	7.9	0.6	0.2	137.0	0.0	0.0	34.7	7.0	34.5	51.2	1.0	54.9	0.0	0.0	351.84	
G	Hotels, Restaurants & Catering	0.0	0.1	0.1	0.6	0.0	0.0	52.2	0.0	0.0	0.0	0.2	148.7	17.8	1.6	1.0	0.0	0.0	223.99	
N	Land Transport	0.0	0.0	0.1	0.3	0.6	0.0	2.4	0.0	0.0	0.0	0.0	0.5	7.2	0.0	0.0	0.0	0.0	20.33	
A	Rail & Air Transport & Transport Support	0.2	0.1	0.1	0.4	0.0	0.0	20.3	0.0	0.0	0.0	0.0	0.8	39.0	2.5	0.0	0.0	0.0	70.03	
C	Sea	0.1	0.3	0.2	0.6	0.2	0.1	1.5	0.0	0.0	0.0	0.0	0.2	0.8	0.3	0.2	0.0	0.0	18.53	
T	Shops & Building Societies	0.3	0.3	0.2	0.6	0.0	0.0	44.4	0.0	0.0	0.0	0.0	0.0	500.6	221.3	313.7	0.0	0.0	1122.19	
I	Insurance Companies	0.1	0.1	0.2	0.2	0.1	0.0	18.5	0.0	0.0	0.0	0.0	0.0	1.4	0.4	3.0	0.0	0.0	29.98	
V	Investment Trusts & Fund Managers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.7	47.6	195.9	0.0	0.0	299.16	
I	Computer Services	0.0	0.1	0.1	0.5	0.0	0.0	0.1	0.0	0.0	1.7	0.0	0.0	3.0	2.1	1.0	0.0	0.0	17.74	
T	Legal Activities	0.1	1.2	0.0	2.2	0.1	0.1	31.4	0.0	0.0	0.0	0.0	0.0	1.9	7.9	0.0	0.0	0.0	85.56	
I	Accountancy	0.2	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	24.4	14.0	38.3	0.0	0.0	85.01	
E	Other Business Activities	0.2	1.5	0.7	3.6	0.5	0.1	6.0	0.0	0.0	0.0	0.0	0.0	5.9	2.1	6.6	0.0	0.0	89.95	
S	Other Services Activities	0.0	0.2	0.1	0.2	0.2	0.1	16.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	25.43	
	Recreation, Culture & Sport	0.0	0.1	0.0	0.0	0.0	0.1	27.1	0.0	3.8	0.0	0.0	3.8	3.9	0.0	3.9	0.0	0.0	42.77	
	Education	0.0	0.0	0.0	0.0	0.0	0.0	22.1	0.0	38.0	0.0	0.0	0.0	0.0	1.4	0.1	0.0	0.0	61.59	
	Health & Social Work & Housing	0.0	0.0	0.0	0.0	0.0	0.0	80.2	0.0	27.6	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	158.23	
	Public Services	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	35.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.77	
	Public Administration & Defence	0.0	0.1	0.0	0.9	0.1	0.0	8.9	0.0	22.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.53	
I	(H) Households	0.0	0.0	0.0	0.0	0.0	0.0	0.0	272.2	102.1	0.0	0.0	0.0	150.4	16.3	76.3	1011.8	142.2	1563.37	
N	(C) Jersey Corporate	0.0	0.0	0.0	0.0	0.0	0.0	12.4	0.0	20.2	0.0	0.0	0.0	0.7	0.5	0.1	0.0	15.2	1650.21	
B	(G) Government (not of commodity trade)	0.0	0.0	0.0	0.0	0.0	0.0	164.4	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	91.4	425.40	
T	Taxes on Expenditure	0.0	0.0	0.0	0.0	0.0	0.0	9.8	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	28.59	
I	Subsidies	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-5.73	
T	(CF) Capital	0.0	0.0	0.0	0.0	0.0	0.0	137.0	170.1	24.3	0.0	0.0	0.0	119.5	132.8	0.0	0.0	0.0	457.18	
U	(E) RUK	0.6	5.4	4.4	9.4	4.4	9.6	447.2	802.6	0.9	196.2	0.0	34.4	0.0	0.0	0.0	0.0	0.0	1665.47	
T	Goods and Services	0.6	5.4	4.4	9.4	4.4	9.6	447.2	0.0	0.0	196.2	0.0	34.4	0.0	0.0	0.0	0.0	0.0	861.94	
I	Transfers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	897.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	803.53	
O	REU	0.0	0.7	0.8	0.1	0.2	0.4	24.3	107.0	0.0	21.2	0.0	1.9	0.0	0.0	0.0	0.0	0.0	176.83	
N	Goods and Services	0.0	0.7	0.8	0.1	0.2	0.4	24.3	0.0	0.0	21.2	0.0	1.9	0.0	0.0	0.0	0.0	0.0	69.81	
H	Transfers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	107.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	107.02	
	ROW	0.0	0.0	1.5	0.0	0.0	0.0	0.8	160.5	0.0	34.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	218.96	
	Goods and Services	0.0	0.0	1.5	0.0	0.0	0.0	0.8	0.0	0.0	34.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	58.43	
	Transfers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	160.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	160.53	
Financ (L)	Income from Employment	13.1	15.4	41.6	79.3	13.1	44.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1011.87	
Expenditure (K)	Other Values Added	9.9	11.8	3.9	39.4	9.19	28.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1679.38	
	Expenditure totals	25.43	42.77	61.59	158.23	35.77	81.53	1563.37	1650.21	448.26	448.97	8.21	239.35	1554.18	134.96	132.77	1011.87	1679.38		

4.3 The Jersey SAM For 1998

All the new entries in the five income-expenditure accounts shown in Table 5.6 map directly to entries for each of the local and external transactors in the Jersey SAM for 1998. I report the SAM in Table 5.7, where the income items are recorded across the rows, and expenditure items down the columns. The SAM entries that use additional information from the income-expenditure accounts are shown as darkly shaded cells in Table 5.7, while the pre-determined IO entries are shown as lightly shaded cells.

Note, however, that I have had to make a couple of adjustments to the IO data in bringing it across to the SAM; these are highlighted in Table 5.7, with four of the IO cells shaded with diagonal lines. I have to adjust the 'Public Services' and 'Public Administration & Defence' entries in the OVA row and GGFC column in order to overcome a problem that occurs when I attempt to map the SAM data into the format required for modelling.

Note from that IO table (Table 5.3) that both the 'Public Services' and 'Public Administration and Defence' sectors show zero entries for OVA. This is due to an IO accounting convention for non-profit making sectors. However, where I want to use the IO accounts and SAM as the database for CGE modelling, this creates a problem in that it is not possible to calculate a capital rental rate for a sector with zero OVA.

The problem is that OVA in each sector represents the return on capital, with the capital rental rate for each sector calculated as OVA divided by capital stock. Therefore, in this context zero OVA means that there is no return on capital or payment for capital services. This does not make sense from a modelling perspective for sectors that are known to employ capital in production activities. Therefore it is necessary in the Jersey case to somehow impose a capital rental rate for these two sectors. I do this by allocating OVA entries that will combine with the level of capital stock estimated for these two sectors (see Section 5.1 below) to produce a plausible capital rental rate. The method I

employ to do this is to take OVA per employee in the other (non-finance¹⁵) production sectors and assume this to apply in the ‘Public Services’ and ‘Public Administration & Defence’ sectors. I did check this against the results of other approaches, such as estimating the average capital rental rate in other sectors of the Jersey economy. However, the OVA per employee method is the only one that produces a capital rental rate that seems plausible.

The other two entries adjusted entries in the SAM shown in Table 5.7 are the ‘Public Services’ and ‘Public Administration & Defence’ entries in the GGFC column. I make this second adjustment in order to maintain the internal balancing requirements of the IO and SAM accounts without having to make adjustments elsewhere in either table. This involves my making the assumption that all capital services employed in these (public) sectors go to meet government’s own final consumption.

5. Additional Data Requirements – Investment Demands And Labour Supply Data

5.1 Investment Demands

The IO table and SAM contain information on which sectors’ outputs are used for the purposes of capital formation. However, what they do not tell us is which sectors the demand for this capital formation comes from. For example, the IO table tells us that 68% of the ‘Quarrying & Construction’ sector’s output is used for capital formation in Jersey. It does not tell us, however, the source of demand for this capital formation. For example, if a bank decides to invest in a new building and contracts a local construction firm to build it, this will enter the IO accounts as a final demand for ‘Quarrying & Construction’ output in the GDFCF column. In other words, what I have so far is the

¹⁵ I exclude the ‘Banks & Building Societies’, ‘Investment Trusts & Fund Managers’ and ‘Insurance Companies’ sectors from this calculation on the basis that OVA per employee is unusually high in these sectors relative to other production activities in Jersey.

supply of capital formation. For CGE modelling I also need to know about the demand for capital formation in the Jersey economy.

In the industrial survey questionnaire (see Appendix 5A) firms are asked for information on their capital expenditure in 1998. Corresponding information is provided by the States of Jersey for public sector activities. This allows me to create a distribution of investment demand across the production sectors of the economy – see Table 5.8 (below) – which is another variable required for the base year data set of the CGE model. Moreover, the distribution of investment demand also allows me to estimate capital stocks. I make the assumption that investment is equal to depreciation in the base year (where all markets are taken to be in long-run equilibrium). Thus, the base year capital stock in each sector is estimated by grossing up on investment demands using the depreciation rate for capital – i.e. dividing each sector's investment demand by the depreciation rate, which I assume, in the absence of econometric estimates to be equal to 0.15 in each sector.

5.2 Labour Supply Data

In Table 5.5 I report the (full-time equivalent, FTE) labour employed by each of the 25 production sectors in the base year, 1998 (sectoral employment is taken from the 1998 Jersey Manpower Database and converted to FTE figures using survey responses on full-time, part-time and seasonal employment). This is sufficient labour market data for a demand-driven general equilibrium model like IO. However, given that I want to move to a more flexible CGE framework with an active supply-side, more information is required on supply conditions in the labour market. Therefore I must augment the existing data shown in Table 5.5 on sectoral labour demands with information on the structure of the aggregate labour market, such as base year working age population, participation rate and unemployment.

Table 5.8 Distribution Of Investment Demand In Jersey, 1998

SECTORS	Distribution of investment demand
Agriculture & Fishing	0.021
Quarrying & Construction	0.024
Total Manufacturing	0.022
Electricity	0.034
Water	0.024
Gas, Oil & Fuel Distribution	0.002
Jersey Telecommunications	0.022
Wholesale & Retail Trade	0.121
Hotels, Restaurants & Catering	0.189
Land Transport	0.003
Sea & Air Transport & Transport Support	0.017
Post	0.002
Banks & Building Societies	0.103
Insurance Companies	0.008
Investment Trusts & Fund Managers	0.059
Computer Services	0.001
Legal Activities	0.014
Accountancy	0.005
Other Business Activities	0.016
Other Services Activities	0.012
Recreation, Culture & Sport	0.013
Education	0.060
Health, Social Work & Housing	0.101
Public Services	0.042
Public Administration & Defence	0.084
Total	1.000

Table 5.9 Jersey Labour Market Statistics 1998

Total labour demand	47,111
Total labour force	47,582
Unemployment	471
Population	89,000
Working age population	55,382
Non-participants	7,800

Source: States of Jersey Manpower Database (1998)

and Fraser of Allander Institute estimates

Total labour demand is given by the total employment figure in Table 5.5. In long-run equilibrium, which the base year database is assumed to represent, the total amount of labour demanded must equal the total amount of labour supplied, which in turn is equal to the total labour force minus the number of unemployed. The total labour force is equal to the working-age population minus non-participants. The States of Jersey have provided me with estimates of total and working age population for 1998. However, no recorded information is available on the number of unemployed and non-participants in Jersey. There is no unemployment benefit system in Jersey and unemployment records are not kept. However, based on observation of labour market conditions, and the absence of unemployment benefits, the States of Jersey assume that the unemployment rate must be very low. Given the observed wealth of many working-age Jersey residents (from non-wage incomes) it appears reasonable to assume that non-participants account for much of the excess of working-age population over total employment in the economy. Therefore, I assume a very small but positive unemployment rate (just under 1%) that appears reasonable based on local knowledge. The labour market data that I use in my modelling database are summarised in Table 5.9.

6. Chapter Summary And Conclusions

This chapter focuses on the first stage of constructing a CGE model for the target economy of Jersey – collection and organisation of the economic dataset. The requirements for constructing the base year economic database for a CGE model are summarised in Section 2. Then, in Section 3 I explain how the first component of this database, an input-output (IO) table for the target economy (Jersey) for the chosen base year (1998) is constructed mainly using survey and other primary data collected for the economy in that year. This is sufficient to move directly to specification and use of the most straightforward type of general equilibrium model – an IO model of the Jersey economy.

However, I then go on to explain how the IO database must be augmented with information on income flows, investment demands and labour supply in the target economy in order to construct a more flexible CGE modelling framework (with IO as the limiting case). Therefore, in Section 4 I go on to discuss the data requirements and construction of a social accounting matrix (SAM) for Jersey, which involves using the IO data along with a set of income-expenditure accounts that provide the necessary information on income flows between the main aggregate transactor groups. I complete the construction of the base year economic database in Section 5 with the incorporation of investment demand and labour supply data.

In the introduction to this chapter I explain that the next stage in Shoven & Whalley's (1984) process of constructing a CGE model is to specify how the variables quantified in the base year dataset relate to each other, in terms of functional form and parameter values. I move onto the stage of model specification in Chapter 8. However, given that the objective of my thesis is to build an *economic-environmental* CGE modelling framework, rather than a standard economic model, I must first construct the base year dataset for the environmental component of the model. This is the focus of the next chapter (Chapter 6), where I illustrate the construction of a set of environmental accounts and coefficients for the case of Jersey.

Chapter 6. Environmental Database Construction

1. Introduction

In Chapter 5 I identify four basic data requirements for the construction of an economic-environmental CGE modelling framework:

1. Base-year input-output (IO) tables for the target economy
2. A social accounting matrix (SAM) for the target economy (incorporating the IO tables and other information on income flows between the main aggregate transactors)
3. Other structural data for the target economy (including base year employment data and investment demands)
4. Base year economic-environmental accounts and environmental coefficients

There I explain that elements 1-3 are the basic *economic* database requirements for standard general equilibrium modelling, and in Chapter 5 I focus on constructing a database incorporating these elements for the empirical example of Jersey (for the base year of 1998). However, if I want to turn my basic economic model into an economic-environmental model, I need to augment this economic database with information on environmental variables. This is my objective in the current chapter, which is structured as follows.

In Section 2 I consider the basic requirements of an environmental database that is to be used for economic-environmental analysis. This involves a discussion of the need for consistency with the economic accounts and the relationship between economic activity and environmental variables. In Section 3 I explain the generation of a set of environmental accounts for Jersey for the chosen base year (1998). Then in Section 4 I use these accounts to identify a set of environmental coefficients for the economic-

environmental model of Jersey that I develop in the next three chapters of this dissertation.

In Section 5 I use the economic–environmental accounts and coefficients constructed here for Jersey to explore a specific example of what is a widely discussed problem in regional accounting and modelling: the appropriateness of region-specific data collection and modelling. I do this by identifying and assessing the degree of added precision gained from estimating and using the Jersey-specific environmental coefficients as compared to those that can be derived using UK data. This exercise also allows an indirect test of whether the Jersey regional economy is similar to that of the UK in terms of its key structural characteristics, and therefore of the value gained from the type of region-specific accounting, modelling and policy analysis that is the focus of my thesis¹. Finally, in Section 6 I provide a chapter summary and conclusions.

2. Environmental Database Requirements

2.1 Consistency Between Economic And Environmental Accounts

I would argue that the key requirement of any database that is to be used for integrated economic–environmental analysis is consistency between the environmental and economic data. To explain, compilation of so-called ‘emissions inventories’ has been common in recent years in many countries. However, the classification of emission sources in these inventories has tended to be inconsistent with the sectorisation of national economic accounts. In my review of the economic–environmental (IO) literature in Chapter 3 I discuss how several authors² have identified the incompatibility of

¹ Jersey is not in fact a region of the United Kingdom (or any other larger nation), as it is an independent self-governing state. However the Jersey economy is very closely integrated with that of the UK, sharing its language, currency, exchange and interest rates. Moreover, the majority of Jersey’s trade flows are with the UK. Therefore, in the absence of region-specific data for Jersey, the UK is generally taken to be the natural choice of a proxy national economy from which to draw estimates of parameter values (where appropriate UK data exist).

² For example, see Gale (1995), Hawdon & Pearson (1995), Lange (1998) and Lenzen (1998).

standard economic accounts with the requirements of economic-environmental modelling as a major problem in tracking and analysing important differential sectoral fuel-use and pollution generation patterns. In particular, the common problem area cited is that of energy sectors generally, and different types of electricity generation in particular. The common conclusion in this type of discussion is that the inherent problem in bringing economic and environmental analysis together is that economic (IO) accounts are not normally designed with the exploration of economic-environmental questions as a major objective. Similarly, I would argue that while emissions inventories do tend to recognise environmental pressure areas in the economy (such as transport activities and different types of electricity generation), they are not compiled either with system-wide analysis of economic-environmental interaction or even consistency with standard economic accounting practices in mind.

Take, for example, the UK Environmental Accounts (UKENA), which report a time series of emissions of a number of air pollutants for a 91-sector Environmental Accounts (EA) breakdown of the economy. The UK national IO accounts are reported for 123-sector breakdown of the economy. While the 91 EA codes do in fact map to the coding of the SIC classification system upon which economic IO accounts are based, the EA system identifies several important polluting activities that take place *within* single SIC categories (while aggregating other SIC sectors with similar direct pollution characteristics). Therefore, if one attempts to undertake any economic-environmental analyses there is a problem in that these two sets of accounts are not entirely consistent with one another. The only attempt to configure the UK IO accounts to match the 91-sector EA breakdown is Vaze's (1997) pilot environmental IO system of the UK for the year 1993. However, this pilot exercise has never been repeated in the UK.

In the case of Jersey, as I explain in Chapter 5, formal national accounting and in particular sectorally disaggregated IO accounting have never been undertaken before the work reported here for 1998. On the other hand, there has been significant work on developing a periodic inventory of emissions for Jersey by the Centre for Energy and the

Environment (CEE) at Exeter University (Coley, 1994). However, the classification of emission sources in this work is that recommended by the Intergovernmental Panel on Climate Change (IPCC) – i.e. industrial, commercial (institutional), residential and agricultural. Within this framework important polluting activities, such as electricity generation, waste incineration, transport and heating, *are* separately identified. The problem is that the IPCC classification of activities is difficult to reconcile with that of economic IO accounts since each type of polluting activity may be conducted in numerous economic sectors (particularly transport and heating).

2.1.1 The NAMEA Framework

There have been useful developments in so-called ‘satellite accounting’ to promote the construction of integrated and consistent economic-environmental accounts. The concept of a ‘National Accounting Matrix including Environmental Accounts’ (NAMEA) was originated in the Netherlands to overcome the types of problem I identify above. The Dutch NAMEA accounts (to date constructed for the period 1987-1998) contain a set of physical environmental accounts on natural resource inputs and residual outputs (waste and pollution) that are connected to the system of national accounts for the Dutch economy (Haan 2001).

As a result of this work in the Netherlands, the statistical office of the European Union (Eurostat) launched a project to develop guidelines for the conversion of resource-use and emissions data to national accounting classifications and definitions. The purpose of this is to promote the development of NAMEA accounts in all EU member states (see Haan 2001). The UK has already developed a trial version of a 76-sector economic-environmental database using the Dutch NAMEA framework. This ‘trial NAMEA table’³ goes some way to reconciling the differences between environmental and economic accounting by aggregating the 91 EA sectors and the 123 UK sectors used in

³ Rocky Harris and Malindi Myers of the Environmental Accounts Branch of Office for National Statistics (ONS) very kindly made this dataset available to me.

UK national accounting to a common 76-sector breakdown of the UK economy. Unfortunately this process involves aggregating some of the economic activities identified by Vaze (1997) as having important differential pollution characteristics (such as different types of electricity generation and waste services) in order to use the SIC classification of activities as a common base. However, the trial NAMEA tables *are* an important innovation for UK national accounting, since they constitute an attempt to organise the economic accounts for the purpose of addressing environmental questions. As yet, no attempt appears to have been made to utilise the UK's trial NAMEA database for any type of modelling exercise for the UK economy⁴. However the Dutch NAMEA has been used for at least one environmental IO application in the Netherlands (see Haan 2001).

Here I adopt a NAMEA-style approach to constructing a set of environmental accounts for Jersey, augmenting the IO accounts, constructed in Chapter 5, with information on the physical use of different types of energy and direct pollution generation for each of the IO production and final demand sectors. While my main motivation for adopting this approach is to provide a consistent economic-environmental database for modelling purposes, it has the added benefit of providing Jersey with a pilot set of NAMEA accounts⁵.

2.2 Assumptions About The Relationship Between Economic Activity And Environmental Variables

There is one key difference in moving from construction of the economic database for an economic-environmental CGE modelling framework to construction of the environmental database. In Chapter 5 I note that specification of how the variables being

⁴ In Section 5 and Appendix 6B I use the UK trial NAMEA database to construct a set of output-pollution coefficients for the UK economy in 1998, which I then adapt for use at the regional level.

⁵ Jersey is not a member of the EU. However the States of Jersey are keen to develop national accounting practices, including satellite accounting for monitoring environmental and general sustainability objectives, that are in line with those used in other economies, particularly the UK.

modelled relate to one another does not have to be considered at the economic database construction stage. However, this is not generally the case when it comes to construction of the environmental database. What I need in terms of the environmental accounts I am constructing here is information on the total flow of emissions (of each pollutant) from each individual production and final demand sector (and final demand group) of the economy to the environment. The problem is that flows of pollutants from any one activity over a given time period (e.g. our base-year of 1998) *cannot generally be directly observed*. Instead these have to be estimated by specifying relationships between economic activities and the generation of pollution and observing appropriate economic variables instead. For example, suppose a relationship has been determined between the use of a fuel, e.g. coal, and the generation of CO₂ in the form of an emissions factor. Flows of CO₂ from any given economic activity to the environment are then estimated by observing coal use during the activity over a given time period and applying the pre-determined emissions factor to this level of coal use.

The implication of this for the construction of the environmental database for this thesis is that I have to make certain assumptions regarding the relationship between economic and environmental variables. The standard assumption adopted in calculating the emissions generated by a given economic activity is that emissions are a linear function of the volume of fuel combusted during that activity *and* of the levels of output from other polluting processes (see for example Beauséjour *et al* (1994), Vaze (1997)). Thus, for each production sector, *i*, emissions of each pollutant, *k*, are determined as:

$$(6.1) \quad P_{k,i} = \sum_{j,t} (e_{ijt}^k \cdot F_{ijt}) + n_i^k \cdot X_i, \quad \forall i = 1, \dots, I, \quad \forall k = 1, \dots, K, \quad \forall j = 1, \dots, J, \quad \forall t = 1, \dots, T$$

Where e_{ijt}^k is an emissions factor, identifying the amount of pollutant *k* that is generated when sector *i* uses (combusts) one unit of fuel *j* using technology/process *t*, F_{ijt} is the physical quantity of fuel *j* used by sector *i* with technology *t*, and n_i^k is an output-

pollution coefficient quantifying the non-fuel-combustion-related generation of pollutant k per unit of output in sector i , X_i^6 .

In the case of final consumers, such as households or tourists, that are responsible for the direct generation of pollution, emissions are determined in the same way for each final demand sector, z (where, instead of total output, emissions are related to total final consumption expenditure, C_z):

$$(6.2) \quad P_{k,z} = \sum_{j,t} (e_{zjt}^k \cdot F_{zjt}) + n_z^k \cdot C_z, \quad \forall z = 1, \dots, Z, \quad \forall k = 1, \dots, K, \quad \forall j = 1, \dots, J, \quad \forall t = 1, \dots, T$$

The IO accounts reported in Tables 5.3 and 5.4 of Chapter 5 give the value of output for each production sector, X_i , and expenditure by each final demand sector, C_z . Therefore, the additional data requirements for estimating pollution-by-sector in Jersey (1998) are estimates of the amount of each type of fuel combusted by each sector using different technologies (F_{ijt} and F_{zjt}) and of the fuel combustion and non-combustion emissions factors (e_{ijt}^k , e_{zjt}^k , n_i^k and n_z^k).

The process of gathering the physical data on energy use and estimating equations (6.1) and (6.2) for each production sector and final demand group for Jersey is explained in Section 3. To complete the environmental database required for an economic-environmental CGE model I also need to construct a set of environmental coefficients that fix the relationship between input use and/or the production of output in the economy. I explain this development in Section 4.

3. Fuel Use And Emissions Generation By Production/Final Demand Sectors In Jersey, 1998

⁶ Non-fuel-combustion-related emissions may be related to input use – for example, fertilisers. However, unless data are available on emissions factors relating the amount of pollution generated to the amount of specific types of inputs used, it is standard practice to relate the amount of pollution generated to the amount output produced.

3.1 Fuel Use By Sector

During the process of constructing the IO table of the Jersey economy (see Chapter 5, Section 3), data were gathered on the amount (in monetary terms) spent by firms and final consumers on four broad fuel types⁷: gas⁸, liquid heating oils, solid heating fuels (coal), and automotive fuels (petrol/diesel). Together, these represent the outputs (total sales) of the ‘Gas, Oil and Fuel Distribution’ sector in the Jersey IO table. Balancing these purchase (demand-side) data with sales data on the supply side is not difficult because a sole gas supplier and a consortium of fuel distributors import all fuels onto the island of Jersey via a single port. Both gave full information on their sales of the different fuel types for the IO table. Moreover, in follow-up interviews that I carried out in Jersey they also provided corresponding information on the physical amount of the various types and sub-types⁹ of fuels supplied to different broad types of user during the base year of 1998. This allows me to estimate the physical amount of each fuel type used by each production and final demand sector on the basis of sales shares from the IO data and information provided by the fuel suppliers/distributors on unit prices charged to different types of user.

The only fuels imported onto the Island by any other agent are the gas oil and heavy fuel oil used in electricity generation. Jersey has a single electricity supplier who provided information on the monetary value and physical amounts of both of these fuels that were imported and used for electricity generation during 1998.

I give a breakdown of physical fuel use by sector and fuel type in Table 6.1.

⁷ Aviation fuels are also imported into Jersey for resale. However, as I explain below, emissions from aircraft are estimated using the concept of counting aircraft movements rather than fuel use.

⁸ Natural gas is not supplied in Jersey; instead a mix of propane and butane is supplied in mains and bottled form.

⁹ For example all the ‘heating oil’ supplied to households is kerosene, while all commercial and public sector users are supplied with gas oil, with some use of light sulphur kerosene and light fuel oil in particular industries.

Table 6.1 Physical Fuel Use By Production Sectors And Final Demand Groups

Fuel Type	Motive Fuels	Non-motive fuels						
User	Petrol/diesel (kilograms)	Kerosene SGK (kilograms)	Kerosene LSK (kilograms)	Gas Oil (kilograms)	Light Fuel Oil (kilograms)	Heavy Fuel Oil (kilograms)	Coal (kilograms)	Mains & Bottled Gas (Megatherms - MTh)
PRODUCTION SECTORS:								
Agriculture & Fishing	1063419		1129384	5839282	6487488			
Quarrying & Construction	2002771			763731				0.0078
Manufacturing	724518			2716051	1263670			0.0665
Electricity	143060			2724418		68170116		
Water	50430							
Gas, Oil & Fuel Distribution	286715							
Jersey Telecommunications	69439			6761				0.0008
Wholesale & Retail Trade	2383484			1059164				0.0597
Hotels, Restaurants & Catering	542560			6923828			50939	1.1210
Land Transport	380541			81760				
Sea & Air Transport & Trans. Supp.	221450			1552497				
Post	52868			105528				
Banks & Building Societies	2086			84014				0.0059
Insurance Companies	25814							
Investment Trusts & Fund Managers	276425			222999				0.0262
Computer Services	78151			3542				
Legal Activities	79045							0.0139
Accountancy	16973							
Other Business Activities	301149							
Other Services Activities	479978				421223			0.0009
Recreation, Culture & Sport	123488			697034				0.3264
Education	40244			664837			288	0.3008
Health, Social Work & Housing	81055			1339027				1.2563
Public Services	11297			186632				0.5719
Public Administration & Defence	1813			29955				0.1723
FINAL DEMAND GROUPS:								
Household Income Group 1	1863377	2503362					770062	0.2271
Household Income Group 2	4926896	3946973					903739	0.2330
Household Income Group 3	5932837	3694986					1766750	0.2891
Household Income Group 4	7570936	5261411					1299162	0.6339
Household Income Group 5	9082839	13884065					869366	0.4913
Tourists	2869444							
TOTAL	41685100	29290797	1129384	25001059	8172382	68170116	5460306	5.8051

Table 6.1 Physical Fuel Use By Production Sectors And Final Demand Groups

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User	Petrol/diesel (kilograms)	Kerosene SGK (kilograms)	Kerosene LSK (kilograms)	Gas Oil (kilograms)	Light Fuel Oil (kilograms)	Heavy Fuel Oil (kilograms)	Coal (kilograms)	Mains & Bottled Gas (Megatherms - MTh)
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Gas, Oil & Fuel Distribution	286715							
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Sea & Air Transport & Trans. Supp.	221450			1552497				
Post	52868			105528				
Banks & Building Societies	2086			84014				0.0059
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Tourists	2869444							
TOTAL	41685100	29290797	1129384	25001059	8172382	68170116	5460306	5.8051

3.2 Combustion Technology And Fuel Use Emissions Factors

The next thing I need to determine is the technology used to combust the various fuel types and the relevant emissions factors. At this stage I am able to draw on previous work that has been done in Jersey by the Centre for Energy and the Environment (CEE) at Exeter University¹⁰ on identifying appropriate emissions factors for the measurement of a number of air pollutants given technologies used in Jersey. The CEE work (Coley, 1994) focuses on compiling an inventory of greenhouse gas emissions by identifying all significant sources of gaseous pollutants identified by the Intergovernmental Panel on Climate Change (IPCC). This involves adapting IPCC and Warren Springs Laboratory (WSL) emissions factors to reflect polluting technology in Jersey and applying these emissions factors to 1990 and 1993 aggregate fuel use data and other non-fuel combustion sources of pollution. Here I draw on this work by applying the emissions factors determined by Coley (1994) to 1998 fuel use data and reporting emissions-by-source at a greater level of sectoral detail than that required for an IPCC inventory¹¹.

With regard to emissions generation from fuel use, the methodology employed by Coley (1994) distinguishes between emissions from mobile and stationary sources. I follow the same distinction here.

3.2.1 Emissions From Motive Combustion (Automotive Fuel Use)

Emissions from mobile combustion depend on fuel and vehicle type (the latter being the relevant form of polluting combustion technology, represented by subscript t in equations (6.1) and (6.2)). Unfortunately, the survey data on fuel use by production sectors and final demand groups in Jersey in 1998 only allows me to determine

¹⁰ I am extremely grateful to Dr David Coley at CEE for his guidance at this stage of the project.

¹¹ The inventory compiled by CEE reports emissions from energy usage for the IPCC-recommended categories of industrial, commercial/institutional, residential and agricultural sources. It also reports what are known as process and area source emissions from solvent and other product use, as well as emissions from human and animal waste and waste incineration. (All of these fall into the category of what I refer to here as non-fuel combustion related pollution).

purchases of an aggregate automotive fuel composed of petrol and diesel. However Coley (1994) identifies mobile combustion emissions factors by *vehicle type* under the assumption that certain types of vehicle (cars, mopeds and motorcycles) only run on petrol, while all others (vans, trucks, buses, coaches, tractors and farm equipment) are diesel fuelled. The Coley (1994) report recommends that this approximation should be improved upon in the future if possible. However, given that the sectorally-disaggregated fuel-use survey data only identify an aggregate automotive fuel, but do include data on vehicle-use by sector, utilisation of the vehicle-use emissions factors (stating grams pollution/kilogram fuel use) is the best option at this time¹².

In Table 6.2 I report the vehicle use emissions factors identified for Jersey by Coley (1994). I convert the survey data on use of the aggregate automotive fuel by each production and final demand sector (given in monetary units) into the appropriate physical units using control total data provided by the consortium of Jersey fuel distributors and information on unit costs¹³. (The results of this process are reported in Table 6.1.) To estimate emissions from automotive fuel use I then apply the emissions factors to the fuel consumption data for each sector/final demand group using weights that reflect the share of each type of vehicle in total vehicle use for that sector/final group¹⁴. I report the results in Table 6.3.

¹² In fact, the assumption adopted in the CEE work that all cars, mopeds and motorcycles are petrol fuelled with all other vehicles being diesel fuelled appears reasonable in the case of Jersey. Control total data supplied by the Jersey Department of Transport tells us that in 1998 just under 85% of registered vehicles were cars, mopeds and motorcycles. Taking this against the control data provided by the consortium of fuel distributors which tells us that in 1998 just under 84% of the petrol/diesel supplied was petrol, the CEE approximation would appear to be fairly reasonable.

¹³ The control total data on different types of fuel supplied are given in litres. However Coley's (1994) emissions factors state emissions per unit of fuel use in terms of mass (kilograms or tonnes). I use volume to mass conversion factors provided to me by CEE to convert the control data to the appropriate units.

¹⁴ There are some gaps in the survey data on vehicle use. I use control total data provided by the Jersey Department of Transport to fill these gaps to ensure as much consistency as possible with the implied pattern of total vehicle use on the Island, particularly the suggested split between petrol between petrol/diesel fuelled vehicles noted in Footnote 12.

Table 6.2 Vehicle-Use Emissions Factors For Jersey

Vehicle Type	Emissions grammes per kilogram fuel ¹					
	CO ₂ as carbon	Methane	NOx	NMVOC	CO	N ₂ O
Motorcycle/mopeds	3172	5.6	3.23	111	405	0.04
Cars	3172	1.38	16.99	50.27	322.56	0.04
Vans & miscellaneous ²	3188	0.1	7.17	4.11	7.96	0.08
Truck	3188	0.26	42.86	7.63	21.8	0.08
Buses and coaches	3188	0.1	7.17	4.11	7.96	0.08
Tractors & farm equipment	3188	0.45	63.5	9.6	25.4	0.08

Source:

Report by the Centre of Energy and the Environment, 'The Estimation of Greenhouse Gas Emissions from Jersey', commissioned by the States of Jersey in 1994

Notes:

1. All motorcycles, mopeds and cars are assumed to be petrol fuelled, and all other vehicles are assumed to be diesel fuelled
2. 'Miscellaneous' vehicles contains earth moving equipment, hoists and motor homes

Table 6.3 Emissions From Motive Fuel Use By Production Sector And Final Demand Group (kilograms)

Pollutant	CO₂ as carbon	Methane	NOx	NM VOC	CO	N₂O
Sector/final demand group						
Agriculture & Fishing	3388181	522	50715	14225	60950	80
Quarrying & Construction	6384305	266	20025	10282	28399	159
Manufacturing	2306830	330	12154	11948	65439	51
Electricity	454917	108	1917	3946	23977	9
Water	160447	32	783	1160	6829	3
Gas, Oil & Fuel Distribution	912873	140	6700	4957	26919	20
Jersey Telecommunications	221169	23	691	875	4552	5
Wholesale & Retail Trade	7582288	1658	53593	59320	348940	150
Hotels, Restaurants & Catering	1725342	419	10427	15134	91165	33
Land Transport	1210730	248	7619	8925	52233	24
Sea & Air Transport & Trans. Supp.	704897	130	6885	4498	24870	15
Post	168533	6	427	249	624	4
Banks & Building Societies	6616	3	35	104	667	0
Insurance Companies	81883	36	439	1298	8327	1
Investment Trusts & Fund Managers	876819	381	4696	13896	89164	11
Computer Services	248062	95	1226	3450	21945	4
Legal Activities	251363	58	955	2149	13063	5
Accountancy	53837	23	288	853	5475	1
Other Business Activities	958203	179	3453	6615	39000	19
Other Services Activities	1527207	286	5504	10543	62159	31
Recreation, Culture & Sport	393097	59	1242	2184	12409	8
Education	128299	4	289	165	320	3
Health, Social Work & Housing	258403	8	581	333	645	6
Public Services	36016	1	81	46	90	1
Public Administration & Defence	5781	0	13	7	14	0
FINAL DEMAND GROUPS:						
Household Income Group 1	5910632	3229	29515	103133	613894	75
Household Income Group 2	15628114	8537	78040	272690	1623177	197
Household Income Group 3	18818959	10280	93974	328366	1954587	237
Household Income Group 4	24015008	13119	119921	419030	2494262	303
Household Income Group 5	28810767	15739	143869	502710	2992362	363
Tourists	9101875	4972	45451	158816	945345	115
Total emissions from automotive fuel use	132331449	60896	701508	1961910	11611801	1933

Table 6.4 Emissions from Aircraft Movements
('Sea & Air Transport and Transport Support' sector)

Estimated aircraft movements	43500						
	CO₂ as carbon	Methane	SO₂	NOx	NMVOC	CO	Black smoke
Emissions factors (kg/movement)	401	0.03	0.27	7.9	2.2	6.2	0.45
Emissions (kg)	17443500	1305	11745	343650	95700	269700	19575

Source (emissions factors and estimated aircraft movements):

Report by the Centre of Energy and the Environment, 'The Estimation of Greenhouse Gas Emissions from Jersey', commissioned by the States of Jersey in 1994

There is one other type of mobile combustion that I have not covered yet: fuel use in private and commercial aircraft. The consortium of fuel distributors did supply information on the total amounts of aviation gas and jet fuel imported and supplied in 1998. However, since the amount of aircraft fuel supplied in any one economy is unlikely to correspond to the amount of fuel combusted within that economy's borders, I adopt the WSL concept of aircraft movements in line with the practice used for Jersey by Coley (1994). An aircraft movement is one landing/takeoff cycle of up to 1000 metres and the WSL emissions factors in Table 6.4 show emissions (in kilograms) generated by one of these movements. The emissions factors that I use for Jersey are defined for a 'small airport' (as opposed to a 'large airport'): this categorisation was made by Coley (1994) on the basis of the mix of different types of aircraft that take off and land at Jersey Airport. In the absence of more up to date information I take the number of movements recorded for 1993 for the current year of study, 1998 (43,500 movements). I report the estimates of emissions from these aircraft movements in Table 6.4 also.

In this study I allocate all direct generations of emissions from aircraft movements to the 'Sea & Air Transport and Transport Support' (SATTs) sector, as Jersey Airport and the local airline are both part of this sector. However, I should point out that this may not be entirely satisfactory: Jersey Aero Club (part of the 'Total Recreation, Culture & Sport' (TRCS) sector) and private flyers (both local and non-local) also purchase aviation gas and fly in and out of Jersey Airport. Therefore some aircraft movements should really be allocated to TRCS, Jersey households and tourists. However, no information is available on how many aircraft movements these groups account for, and, due to the problem discussed in the previous paragraph, it is not possible to make an allocation based on shares in fuel purchases. This is a problem that should be rectified if and when better data become available¹⁵.

¹⁵ There is another problem relating to the attribution of emissions from air, as well as land, transport activities to tourists. In Chapter 7 I use the environmental IO system to attribute emissions from production activities to different types of final demand. Tourists visiting Jersey are important users of all transport services. However, given that intending tourists tend to purchase these services via agents in

One other area of mobile fuel combustion that I do not cover here is emissions from shipping. Coley (1994) does not make any attempt to identify fuel used in shipping activities due to a lack of specific data in this area. However, a previous study of energy supply and use in Jersey (Burek, 1988) finds that shipping represents a relatively small proportion of fuel use in the economy. Moreover, as with the case of air transport, there are problems in determining how much of the fuel supplied to marine users can actually be classified as being combusted within the economy's borders. However, at such a time as appropriate data do become available, I hope that emissions from shipping and marine fuel use can be separately identified and accounted for in Jersey.

3.2.2 Emissions From Stationary Sources (Non-Motive Fuel Use)

In Jersey stationary combustion of fuels is mainly for heating purposes. In the absence of natural gas being piped to the Island, most heating systems are oil powered and the consortium of fuel suppliers have been able to provide me with a detailed breakdown of what type of fuels are used by different types of consumers. Kerosene is supplied solely for use in domestic (household) heating systems, while most commercial and public sector heating systems run on gas oil. There is also some use of light fuel oil in the commercial sector: in greenhouses in the 'Agriculture & Fishing' sector, in breweries and the Jersey Milk Marketing Board (both 'Manufacturing'), and in dry cleaning activities (part of 'Other Service Activities'). Low sulphur kerosene (LSK) is also used for CO₂ enrichment in greenhouses in the 'Agriculture & Fishing' sector. There is also domestic and commercial use of gas for heating purposes (gas is also used for CO₂ enrichment by farmers). Natural gas is not piped directly to Jersey; rather the gas supplied on the Island takes the form of liquid petroleum gas (LPG), a mix of propane or butane with air mixed to give the same calorific value as natural gas. Finally, there is

their home countries, outputs and emissions from transport sectors in Jersey cannot be attributed to tourist demand in a conventional single-region IO system.

some limited use of coal by households and the 'Education' and 'Hotels, Restaurants & Catering' sectors.

I give a breakdown of the amounts of each type of stationary (non-motive) fuel use by each production and final demand sectors in the appropriate physical units in Table 6.1 (alongside automotive fuel use).

Coley (1994) identifies appropriate emissions factors for the use of each of these fuels for heating purposes, which I report in Table 6.5. I apply these to the physical fuel use data in Table 6.1 to produce the estimates of emissions from stationary fuel use by sector and final demand group that are reported in Table 6.6.

The only emissions from stationary fuel use that I do not report in Table 6.6 is the pollution generated by the use of gas oil and heavy fuel oil in the 'Electricity' sector. Emissions from electricity generation tend to be a major source of pollution generation in most economies. In Jersey this is particularly true due to the emissions intensity of oil-powered generation (relative to alternative types of electricity generation as well as other sources of pollution on the Island). Therefore I treat this form of emissions generation from stationary fuel use separately.

The IPCC and WSL identify separate emissions factors for combustion of fuels in power stations (the technology is quite different to that used in home heating systems for the combustion of, for example, gas oil). The Jersey Electricity Company supplied me with information on the amount of oil used for the generation of electricity for the year 1998: a combination of gas oil and heavy fuel oil is used, but the mix is dominated by the latter. In Table 6.7 I detail the amount of oil used, the relevant emissions factors, and the resulting estimates of pollutants generated during electricity generation in 1998.

Table 6.5 Stationary Fuel-Use Emissions Factors For Jersey
(excluding those associated with fuel use in electricity generation)

Heating Oils						
Fuel Type	Emissions kilograms/tonnes fuel					
	CO ₂ as					
	carbon	Methane	SO ₂	NO _x	NMVOC	CO
Kerosene	859	0.000875	0.2	2.1	0.069	0.16
Gas oil	857	0.000875	4.2	4.5	0.069	0.24
LFO	850	0.00075	43.6	7.4	0.059	0.5
Coal	677	0.125	20.8	1.5	9.88	45
Gas						
Fuel Type	Emissions kilograms/megatherms (MTh) gas					
	CO ₂ as					
	carbon	Methane	SO ₂	NO _x	NMVOC	CO
Gas (LPG)	1870000	10.6	n/a	5280	834	863

Source:

Report by the Centre of Energy and the Environment, 'The Estimation of Greenhouse Gas Emissions from Jersey',
 commissioned by the States of Jersey in 1994

Table 6.6 Emissions From Stationary Fuel Use By Production Sector And Final Demand Group (kilograms)
(excluding emissions associated with fuel use in electricity generation)

Pollutant	CO₂ as carbon	Methane	SO₂	NOx	NMVOC	CO
Sector/final demand group						
Agriculture & Fishing	11488771	10.963	307605	76656	864	4826
Quarrying & Construction	669050	0.751	3208	3478	59	190
Manufacturing	3526210	4.030	66503	21925	317	1341
Electricity	0	0	0	0	0	0
Water	0	0	0	0	0	0
Gas, Oil & Fuel Distribution	0	0	0	0	0	0
Jersey Telecommunications	7380	0.015	28	35	1	2
Wholesale & Retail Trade	1019329	1.560	4448	5081	123	306
Hotels, Restaurants & Catering	8064555	24.309	30140	37153	1916	4921
Land Transport	70069	0.072	343	368	6	20
Sea & Air Transport & Trans. Supp.	1330490	1.358	6520	6986	107	373
Post	90437	0.092	443	475	7	25
Banks & Building Societies	83002	0.136	353	409	11	25
Insurance Companies	0	0	0	0	0	0
Investment Trusts & Fund Managers	240192	0.473	937	1142	37	76
Computer Services	3036	0.003	15	16	0	1
Legal Activities	25905	0.147	0	73	12	12
Accountancy	0	0	0	0	0	0
Other Business Activities	0	0	0	0	0	0
Other Services Activities	359747	0.326	18365	3122	26	211
Recreation, Culture & Sport	1207713	4.070	2928	4860	320	449
Education	1132410	3.806	2798	4580	300	432
Health, Social Work & Housing	3496852	14.489	5624	12659	1140	1406
Public Services	1229438	6.226	784	3860	490	538
Public Administration & Defence	347939	1.853	126	1045	146	156
FINAL DEMAND GROUPS:						
Household Income Group 1	3096486	100.856	16518	7611	7970	35249
Household Income Group 2	4438065	118.891	19587	10875	9396	41501
Household Income Group 3	4910737	227.142	37487	11936	17952	80344
Household Income Group 4	6584532	173.719	28075	16345	13727	59851
Household Income Group 5	13298344	101.027	16700	32755	7981	32767
Tourists	0	0	0	0	0	0
Total emissions from stationary fuel use	66720689	796	569536	263444	62908	265023

Table 6.7 Emissions From Electricity Generation In Jersey

Gas oil used (tonnes)		2724					
Emissions factors (emissions kg/tonnes fuel)	CO₂ as carbon	Methane	SO₂	NOx	NMVOC	CO	Black Smoke
	850	0.00113	57.7	10.7	0.889	1.27	1
Emissions (kg)		2315755	3.08	157199	29151	2422	3460
Fuel oil used (tonnes)		68170					
Emissions factors (emissions kg/tonnes fuel)	CO₂ as carbon	Methane	SO₂	NOx	NMVOC	CO	Black Smoke
	857	0.000875	4.2	11.4	0.069	0.24	0.75
Emissions (kg)		58421789	59.65	286314	777139	4704	16361
Total emissions from electricity generation (kg)	CO₂ as carbon	Methane	SO₂	NOx	NMVOC	CO	Black Smoke
	60737545	62.73	443513	806291	7126	19821	53852

Source (emissions factors):
Report by the Centre of Energy and the Environment, 'The Estimation of Greenhouse Gas Emissions from Jersey', commissioned by the States of Jersey in 1994

3.3 Sector Specific Non-Fuel-Combustion Related Emissions

The Jersey economy has a very small manufacturing sector, with none of the heavy industries where production processes themselves are often pollution intensive (independent of energy use). I would therefore expect emissions from fuel/energy use to be the main source of pollution in Jersey. In other words, I would expect $n^k_i \cdot X_i$ and $n^k_z \cdot C_z$ generally to be zero so that equations (6.1) and (6.2) collapse to (6.1') and (6.2') across most sectors and final demand groups respectively:

$$(6.1') \quad P_{k,i} = \sum_{j,t} (e^k_{ijt} \cdot F_{ijt})$$

$$(6.2') \quad P_{k,z} = \sum_{j,t} (e^k_{zjt} \cdot F_{zjt})$$

where the e^k_{ijt} and e^k_{zjt} are the fuel use emissions factors identified in Tables 6.2, 6.4, 6.5 and 6.7. The F_{ijt} and F_{zjt} are the physical amounts of fuel used in the production of output/total final demand expenditure in 1998 as identified in Tables 6.1, 6.4 and 6.7 (with aircraft movements as a proxy for fuel use in Table 6.4). Thus, in most cases I find the $P_{k,i}$ and $P_{k,z}$ by summing the elements reported in Tables 6.3, 6.6 and 6.7 for each pollutant, k , and sector, i , and final demand group, z . I report the results of calculating equation (6.1') for each production sector and equation (6.2') for each final demand sector in Table 6.8.

However, there are several sources of pollution in Jersey that are not related to the combustion of fuels, and I now consider these. In the sectors and final demand groups where this is the case, I estimate $p_{k,i}$ and $p_{k,z}$ using the full version of equations (6.1) and (6.2) (i.e. by including the additional non-fuel combustion related element, $(n^k_i \cdot X_i$ and $n^k_z \cdot C_z)$).

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Table 6.8 Total Emissions From Fuel Use By Production Sector And Final Demand Group (kilograms)

Pollutant	CO₂ as carbon	Methane	SO₂	NOx	NM VOC	CO	N₂O	Black smoke
Sector/final demand group								
Agriculture & Fishing	14876951	533.3	307605	127371	15089	65776	80.07	53852
Quarrying & Construction	7053355	267.2	3208	23503	10341	28589	158.90	
Manufacturing	5833040	334.3	66503	34079	12266	66780	50.63	
Electricity	61192462	170.5	443513	808207	11072	43798	8.55	
Water	160447	32.0	0	783	1160	6829	3.23	
Gas, Oil & Fuel Distribution	912873	140.3	0	6700	4957	26919	20.00	
Jersey Telecommunications	228548	23.4	28	726	876	4554	5.05	
Wholesale & Retail Trade	8601617	1660.0	4448	58675	59443	349246	150.03	
Hotels, Restaurants & Catering	9789897	443.2	30140	47580	17050	96087	32.55	
Land Transport	1280799	248.2	343	7987	8931	52253	24.35	
Sea & Air Transport & Trans. Supp.	19478887	1436.8	18265	357521	100305	294942	15.00	19575
Post	258970	6.3	443	902	256	649	4.21	
Banks & Building Societies	89617	3.0	353	444	115	692	0.08	
Insurance Companies	81883	35.6	0	439	1298	8327	1.03	
Investment Trusts & Fund Managers	1117011	381.9	937	5839	13933	89240	11.06	
Computer Services	251098	94.6	15	1242	3450	21946	3.54	
Legal Activities	277268	58.6	0	1028	2161	13075	4.74	
Accountancy	53837	23.4	0	288	853	5475	0.68	
Other Business Activities	958203	179.5	0	3453	6615	39000	19.45	
Other Services Activities	1886954	286.4	18365	8626	10568	62370	30.99	
Recreation, Culture & Sport	1600810	62.9	2928	6102	2504	12858	8.43	
Education	1260709	7.8	2798	4869	465	752	3.22	
Health, Social Work & Housing	3755255	22.6	5624	13240	1473	2051	6.48	
Public Services	1265454	7.4	784	3941	536	628	0.90	
Public Administration & Defence	353719	2.0	126	1058	153	170	0.15	
FINAL DEMAND GROUPS:								
Household Income Group 1	9007117	3329.7	16518	37127	111103	649143	74.54	
Household Income Group 2	20066179	8656.3	19587	88915	282086	1664678	197.08	
Household Income Group 3	23729696	10507.6	37487	105910	346318	2034931	237.31	
Household Income Group 4	30599540	13292.7	28075	136266	432758	2554113	302.84	
Household Income Group 5	42109111	15839.8	16700	176623	510691	3025129	363.31	
Tourists	9101875	4972.2	0	45451	158816	945345	114.78	
Total emissions from fuel use (kg)	277233182	63060	1024795	2114893	2127643	12166345	1933	73427

3.3.1 Emissions From Waste Incineration In The ‘Public Services’ Sector

Jersey has a waste incinerator that burns approximately 70,000 tonnes¹⁶ of domestic, commercial and agricultural waste each year. This is the main source of non-fuel combustion related emissions on the Island. In Table 6.9 (below) I report the WSL emissions factors for waste incineration for waste from three different sources: domestic, industrial and agricultural. The only information that is available about the breakdown between these three sources in Jersey is that around 50% of total waste incinerated is domestic waste collected by regular collection with the remainder being delivered to the incinerators site in special deliveries that include items such as building waste. Therefore, for the breakdown shown in Table 6.9, I assume a split with shares 0.5/0.4/0.1 between domestic/industrial/agricultural waste. However, I acknowledge that this is somewhat arbitrary and stress that it is open to revision if and when better information becomes available. For now, I make the 0.4/0.1 split of the 0.5 residual after domestic waste is accounted for on the basis of ‘Agriculture & Fishing’ being a more heavily polluting sector in general than other ‘industrial’ activities in Jersey. (While only directly accounting for about 2% of industrial output, ‘Agriculture & Fishing’ accounts for, on average, around 20% of direct emissions generation from production, in terms of kilograms emitted). I report the estimates of emissions from waste incineration in Table 6.9.

There would be another advantage of identifying sources of waste in the Jersey economy. If it were possible to determine the amount of waste produced by each of the production sectors and final demand groups identified in this study this would allow me to construct a set of output- (expenditure) waste coefficients for each group. Waste generation is an important issue, particularly in a small economy where the options for waste disposal are limited. Therefore it would be useful to be able to attribute the

¹⁶ The estimated figure for the total amount of waste burned each year in the incinerator was taken from the CEE report (Coley, 1994).

production of waste to specific types of activity and sources of demand in the same way as I do for the generation of air pollutants in Chapter 7.

In Table 6.9 I also report the implied process emissions per £1million of 'Public Services' output – i.e. the n_i^k coefficients in equation (6.1). I derive these simply by dividing the emissions estimates for each pollutant, k , by 'Public Services' gross output from the IO table (Table 5.3).

3.3.2 Process Emissions (NMVOCs) From Solvent Use In The 'Manufacturing' And 'Other Service Activities' Sectors

There are two production activities in Jersey for which I am able to estimate process emissions from solvent use: printing (part of the 'Manufacturing' sector) and dry cleaning (part of 'Other Service Activities'). Solvent products contain non-methane volatile organic compounds that are emitted as a result of a chemical evaporation that takes place when these products are exposed to the air during use. Coley (1994) notes that the emissions factor data for this type of process are poor, and that it is difficult to measure the rate of use for the type of solvent products involved. In the current study I have the further problem of identifying which sectors/final demand groups use the various types of solvent products that generate this type of emissions. For example, Coley (1994) considers emissions from paint and adhesive use. However, it is difficult to determine or allocate the use of such products to the sectors and final demanders that I identify here because data on product use have not been collected at a sufficiently detailed level in the household or industrial surveys to allow this. Therefore here I limit my attention to emissions from activities identified in Coley's (1994) study that can be clearly allocated to individual SIC sectors: printing (part of SIC activity 22) and dry cleaning (part of SIC activity 93). However I do acknowledge that this means that my estimation and analysis of NMVOC process emissions is likely to be significantly circumscribed.

Table 6.9 Emissions from Waste Incineration
('Public Services' sector)

Estimated average tonnage waste incinerated per annum¹		70000				
<i>Assumed breakdown by type of waste:</i>						
Domestic		35000				
Industrial		28000				
Agricultural		7000				
		CO ₂ as				
		carbon	Methane	NOx	NMVOC	CO
Domestic waste emissions factors (kg/t)		200	0.009	1.5	0.74	17.5
Emissions from domestic waste (kg)		7000000	315	52500	25900	612500
Industrial waste emissions factors (kg/t)		194	0.09	1	7.4	10
Emissions from industrial waste (kg)		5432000	2520	28000	207200	280000
Agricultural waste emissions factors (kg/t)		200	0.081	1.5	6.1	31.2
Emissions from agricricultural waste (kg)		1400000	567	10500	42700	218400
Total emissions from incineration (kg)		13832000	3402	91000	275800	1110900
Implied emissions kg/£1million sectoral output²		520420	128	3424	10377	41797

Source (emissions factors):
Report by the Centre of Energy and the Environment, 'The Estimation of Greenhouse Gas Emissions from Jersey', commissioned by the States of Jersey in 1994

- Notes:
- Figure for estimated average tonnage of waste incinerated per annum from CEE report and confirmed by Dr Michael Romeril, Environmental Adviser, States of Jersey. The split between domestic, industrial and agricultural waste is an approximation based on the share of domestic/ non-domestic waste incinerated in past years.
 - Implied emissions kg/£1million sectoral output is the n^k coefficient from equation [6.1] in the text, calculated by dividing total emissions from this source by total 'Public Services' output from the Table 5.3 (IO table).

Table 6.10 Process Emissions (of NMVOCs) From Solvent Use

'Manufacturing' sector:	
Estimated NMVOC emissions from printing in Jersey (kg) ¹	59.04
Implied emissions kg/£1million sectoral output ²	0.588
'Other Services Activities' sector:	
Estimated NMVOC emissions from dry cleaning in Jersey (kg) ¹	8.49
Implied emissions kg/£1million sectoral output ²	0.334

- The method of estimating NMVOC emissions from solvent use in industrial processes is explained in the text, Section 3.3.2
- Implied emissions kg/£1million sectoral output is the n^k coefficient from equation [6.1] in the text, calculated by dividing total emissions from this source by total sectoral output from the Table 5 in Chapter 5 (IO table) for the 'Manufacturing' and 'Other Service Activities' sectors respectively .

As I note above, there are problems with regard to identifying and measuring use rates for the solvent products that give rise to NMVOC process emissions. Coley (1994) takes emissions from printing and dry cleaning activities in Jersey (estimated for 1990 and 1993) to be equal to estimates for the UK, with an adjustment for the difference in population between the UK and Jersey (Coley 1994). (This is the manner in which Coley (1994) adjusts for the difference in relative size of the UK and Jersey economies¹⁷.) For the year 1998 UK estimates of emissions for these specific activities are not available, only for the aggregate SIC sectors (SIC 22 and 93) to which printing and dry cleaning activities belong. Instead I assume that the share of Coley's (1994) estimates of UK NMVOC emissions from printing and dry cleaning activities in total NMVOC emissions for 1990 and 1993 from SIC activities 22 and 93 also applies in 1998. Then, as in Coley's (1994) study, I adjust the resulting UK estimates for differences in population (in the absence of better data on the relative size of these activities in the UK and Jersey economies) to get estimates of NMVOC process emissions from printing and dry cleaning. I report these estimates in Table 6.10. In Table 6.10 I also report the implied process emissions per £1million of 'Manufacturing' and 'Other Service Activities' output – i.e. the n^k_i in equation (6.1), where $k = \text{NMVOC}$.

3.3.3 Biological Emissions (Methane) From Animals And Human Beings In The 'Agriculture & Fishing' Sector And By Local Households And Tourists

The final type of non-fuel combustion related emissions that I consider here are methane emissions from animals (that are used in production) and human beings (who participate in economic activity as consumers and as suppliers of labour inputs to production).

Taking emissions from the 'Agriculture & Fishing' sector first, animals that are used to produce agricultural output emit methane both during rumination/digestion and from their waste. Coley (1994) identifies emission rates (kilograms of pollution per year per

¹⁷ A better approach might be to adjust the figures using the difference in GDP or consumption between Jersey and the UK. I follow Coley's (1994) approach to maintain consistency across the two studies.

animal) for both these forms of methane generation from the different types of animal used in agricultural production in Jersey. I report these emissions factors in Table 6.11 (below). In the absence of information on animal numbers for 1998 I assume that these are equal to the average numbers for the period 1989-1993, the period studied by Coley (1994). Applying the emissions factors for each type of animal and summing across both types of animal emissions I get estimates of the total biological emissions from animals, which are also reported in Table 6.11.

In the case of human beings, Coley (1994) identifies an emissions factor for the generation of methane from human waste on Jersey in terms of kilograms of emissions per tonne of dry solid (tDS) content. I estimate the amount of waste in dry solid form for 1998 by taking the implied per capita generation of human waste from Coley's (1994) estimate for 1991 - 0.0363 tonnes¹⁸ - and applying this to the 1998 population estimate of 89,000. By applying the methane emissions factor (31kg/tDS) to the resulting estimate for total human waste (3229.88 tonnes) I estimate methane emissions from human waste as 100126 kilograms – see Table 6.12 (below).

The next step is to allocate these emissions among the human groups of tourists (consumers) and households (consumers and providers of labour services) for the year 1998¹⁹. First, in order to allocate a share of total human waste produced in 1998 to tourists, I take the total number of tourists and the average length of stay on the Island to estimate the effective number of additional people staying in Jersey for the whole of the year²⁰. This figure (8310.7 people) as a share of total effective population (tourists plus

¹⁸ Coley's (1994) estimate of human waste in dry solid form for 1991 is 3051.4 tonnes, and in 1991 Jersey's population was 84,082.

¹⁹ Note that this method is consistent with Coley's (1994) approach, where no account appears to be taken of *additional* human waste generated by tourists. This would be justified if it were thought that the additional effective population in any year from tourists spending time in Jersey is offset by Jersey residents leaving the Island for vacations etc. An alternative approach would be to estimate the amount of human waste generated by tourists in addition to that of the existing population. However, the impact on my estimate of total methane emissions would be less than 1%. Therefore, here I adopt Coley's (1994) approach to maintain consistency with the earlier study.

²⁰ Jersey Tourism report that 543, 623 people visited the Island in 1998, each staying an average of 5.58 days (0.0153 of one year). Thus, the effective number of additional people staying in Jersey for the whole

residents) suggests that 8.54% of human waste, and therefore methane emissions from human waste, can be allocated to tourists. I allocate the remainder between the five household income bands simply by allocating 20% to each: the income bands are quintiles each containing the same number of households, so the assumption I am adopting here is that each band contains households of the same average size. Thus, here I simply link the amount of waste produced to the total number of resident households and tourists. However in the future it may be more appropriate to link human waste more directly to population, using information on average household size within each income band, and the number of visitors to the Island, and/or by linking particular types of consumption (e.g. food) to methane generation per person.

3.3.4 Other Potential Sources Of Non-Fuel-Combustion Related Emissions

Coley (1994) identifies several other types of sector-specific non-fuel-combustion pollution generation in Jersey. For example, in Section 3.3.2 I explain that there will be NMVOC emissions from paint and adhesive use in Jersey, but that I am unable to satisfactorily quantify these at this time. Another example is that farmers in the Agriculture & Fishing sector in Jersey are known to be responsible for N₂O generation from fertiliser use. However, it has not been possible to identify suitable data on the physical use of fertilisers or emissions factors for this activity in either this or the Coley (1994) study of pollution generation in Jersey. I draw the reader's attention to these omissions (along with others in this section, such as emissions from shipping, as discussed in sub-section 3.2.1 above) for the purpose of transparency in reporting the environmental accounting work in this chapter. Also I wish to highlight areas where I hope improvements can be made in future accounting work for Jersey.

of the year was $[0.0153 \text{ times } 543,623] = 8310.7$. With a total resident population of 89,000 this implies that the effective population, including tourists was $[89,000 + 8,311] = 97,311$. The effective additional (tourist) population is a $[8,311/97,311] = 0.0854$ share of this total.

**Table 6.11 Biological Emissions (of Methane) From Livestock
(‘Agriculture & Fishing’ sector)**

	Emissions factor (kg/yr per animal)	Number of animals ¹	Methane emissions (kg)
Methane emissions from livestock			
Cattle - dairy in milk	95	3837	364515
Cattle - other	56.1	2574	144401
Pigs	1.5	655	983
Poultry	0.05	21099	1055
Sheep	8	293	2347
Horses (agricultural)	18	40	727
Total methane emissions from livestock			514029
Methane emissions from animal wastes			
Cattle - dairy in milk	54.8	3837	210268
Cattle - other	24.9	2574	64093
Pigs	2.47	655	1618
Poultry	0.11	21099	2321
Sheep	3.81	293	1118
Horses (agricultural)	30.4	40	1228
Total methane emissions from animal waste			280645
Total biological emissions from agriculture			794674
Implied emissions kg/£1million sectoral output ²			14001

Source (emissions factors):

Report by the Centre of Energy and the Environment, 'The Estimation of Greenhouse Gas Emissions from Jersey', commissioned by the States of Jersey in 1994

Notes:

1. The number of each type of animal used in agriculture in 1998 has been assumed to be equal to the average between 1989 and 1993, the last years for which numbers were available.
2. Implied emissions kg/£1million sectoral output is the nth coefficient from equation [6.1] in the text, calculated by dividing total emissions from this source by total 'Agriculture & Fishing' output from the Table 5.3 in Chapter 5 (IO table).

**Table 6.12 Biological Emissions (of Methane) From Human Beings
(Local households and tourists)**

Methane emissions from human waste:						
Estimated amount of total dry solid human waste (tonnes) in 1998 ¹	3229.88					
Emissions factor - kilograms methane/tonnes dry solid human waste)	31					
Estimated methane emissions from human waste (kg)	100126					
	All households	Household Income Group 1	Household Income Group 2	Household Income Group 3	Household Income Group 4	Household Income Group 5
Methane emissions from HH human waste (kg)²	91575	18315	18315	18315	18315	18315
Implied emissions kg/£1million final demand expenditure by households ³	86.5	229.0	130.4	95.1	68.9	48.2
Methane emissions from tourists' human waste (kg)²	8551					
Implied emissions kg/£1million final demand expenditure by tourists ³	35.7					

Source (emissions factors):

Report by the Centre of Energy and the Environment, 'The Estimation of Greenhouse Gas Emissions from Jersey', commissioned by the States of Jersey in 1994

Notes:

1. The estimated amount of total dry solid human waste in 1998 is based on the CEE estimate for 1991, adjusting for increased population.
2. The method of allocating total human waste between local households and visitors to Jersey is fully explained in the text (Section 3.3.3). With regard to the allocation of household waste among the five income bands, given that these are quintiles 20% is allocated to each group (ie assuming that each band contains households of the same average size).
3. Implied emissions kg/£1million sectoral output is the n_z^k coefficient from equation [6.2] in the text, calculated by dividing total emissions from this source by total final demand expenditure for each group from Tables 5.3 and 5.4 in Chapter 5.

Table 6.13 Total Emissions By Production Sector And Final Demand Group (kilograms¹)

Pollutant	CO ₂ as carbon	Methane	SO ₂	NOx	NM VOC	CO	N ₂ O	Black smoke	GWP Index ¹
Sector/final demand group									
Agriculture & Fishing	14876951	795207	307605	127371	15089	65776	80.07	53852	31601128
Quarrying & Construction	7053355	267.2	3208	23503	10341	28589	158.90		7108226
Manufacturing	5833040	334.3	66503	34079	12325	66780	50.63		5855754
Electricity	61192462	170.5	443513	808207	11072	43798	8.55		61198692
Water	160447	32.0	0	783	1160	6829	3.23		162119
Gas, Oil & Fuel Distribution	912873	140.3	0	6700	4957	26919	20.00		922019
Jersey Telecommunications	228548	23.4	28	726	876	4554	5.05		230606
Wholesale & Retail Trade	8601617	1660.0	4448	58675	59443	349246	150.03		8682985
Hotels, Restaurants & Catering	9789897	443.2	30140	47580	17050	96087	32.55		9809295
Land Transport	1280799	248.2	343	7987	8931	52253	24.35		1293561
Sea & Air Transport & Trans. Supp.	19478887	1436.8	18265	357521	100305	294942	15.00	19575	19513710
Post	258970	6.3	443	902	256	649	4.21		260406
Banks & Building Societies	89617	3.0	353	444	115	692	0.08		89706
Insurance Companies	81883	35.6	0	439	1298	8327	1.03		82951
Investment Trusts & Fund Managers	1117011	381.9	937	5839	13933	89240	11.06		1128459
Computer Services	251098	94.6	15	1242	3450	21946	3.54		254181
Legal Activities	277268	58.6	0	1028	2161	13075	4.74		279970
Accountancy	53837	23.4	0	288	853	5475	0.68		54540
Other Business Activities	958203	179.5	0	3453	6615	39000	19.45		968000
Other Services Activities	1886954	286.4	18365	8626	10577	62370	30.99		1902576
Recreation, Culture & Sport	1600810	62.9	2928	6102	2504	12858	8.43		1604743
Education	1260709	7.8	2798	4869	465	752	3.22		1261871
Health, Social Work & Housing	3755255	22.6	5624	13240	1473	2051	6.48		3757739
Public Services	15097454	3409.4	784	94941	276336	1111528	0.90		15169331
Public Adminstration & Defence	353719	2.0	126	1058	153	170	0.15		353807
FINAL DEMAND GROUPS:									
Households (aggregate)	125511644	143201	118367	544840	1682956	9927995	1175		128883141
Household Income Group 1	9007117	21644.7	16518	37127	111103	649143	74.54		9484763
Household Income Group 2	20066179	26971.3	19587	88915	282086	1664678	197.08		20693669
Household Income Group 3	23729696	28822.6	37487	105910	346318	2034931	237.31		24408538
Household Income Group 4	30599540	31607.7	28075	136266	432758	2554113	302.84		31357181
Household Income Group 5	42109111	34154.8	16700	176623	510691	3025129	363.31		42938990
Tourists	9101875	13523.4	0	45451	158816	945345	114.78		9421447
Total emissions (kg)	291065182	961262	1024795	2205893	2403511	13277245	1933	73427	311850966

Notes:

1. The GWP (Global Warming Potential) Index is a weighted sum of CO₂ (weight 1), methane (weight 21) and N₂O (weight 310): it therefore should not be read as 'kilograms' but simply as an index that is comparable across sectors within an economy and across different economies.

Table 6.14 The Jersey National Accounting Matrix Including Environmental Accounts (NAMEA) For 1998

					Consumption of local goods/services (£million) 1998 current prices (£million)	Consumption of imported goods/services (£million) 1998 current prices (£million)	Value Added (£million) 1998 current prices (£million)	Gross Output (£million) 1998 current prices (£million)	Employment Numbers employed (full-time equivalent)	GWP index	Carbon Dioxide CO2 as carbon (kg)	Methane CH4 (kg)	Sulphur Dioxide SO2 (kg)	Nitrous Oxide NOx (kg)
Sector	SIC code	EA code	NAMEA code	Production Sectors:										
1	01.05	1.3	1.3	Agriculture & Fishing	22.775	5.325	34.387	56.756	2040	31601128	14876951	795207	307605	127371
2	14.05	7.08	7.08	Quarrying & Construction	32.217	19.558	176.516	228.699	4745	7108226	7053355	267	3208	23503
3	10-18, 20, 22-26, 28-31, 33, 34, 37	8-11,13,15,17,19,21,23,25,27,29,31,33,35,37,41,43,45,47	8-11,13,15,17,19,21,23,25,27,29,31,33,35,37,41,43,45,47	Total Manufacturing	29.142	27.606	43.691	100.451	2132	5853754	5833040	334	64803	34079
4	49.1	71-88	71	Electricity	1.753	13.740	28.610	46.684	426	61198692	61192462	170	443513	806207
5	41	87	87	Water	5.374	1.107	6.091	12.472	116	162119	160447	32	0	783
6	42,29,39,42,48	89,91,93	89,91,93	Gas, Oil & Fuel Distribution	2.298	0.510	6.245	14.873	206	922019	912873	140	0	6700
7	44.3	72	72	Jersey Telecommunications	10.023	7.062	25.457	42.544	445	230606	228548	23	28	726
8	54-56	89,94,95	89,94,95	Wholesale & Retail Trade	62.286	24.168	257.963	351.844	7487	8682985	8601617	1660	4448	58675
9	55	43	54	Hotels, Restaurants & Catering	63.796	8.561	82.882	223.992	6024	9809295	9789897	443	30140	47580
10	40.2, 40.3	44-48	56	Land Transport	4.046	1.801	14.486	20.334	410	1293561	1280799	248	343	7987
11	41,42,43	49,70,71	57,58,59	Sea & Air Transport and Transport Support	5.138	9.692	55.194	70.028	908	19513710	19478887	1437	18265	357521
12	64.1	73	60	Post	3.859	0.856	14.618	18.533	363	260406	258970	6	443	902
13	65,121,65.31,65.32,65.33,65.34,65.35 & 65.36	74	61	Banks & Building Societies	11.781	43.182	1067.292	1122.194	5757	89706	89617	3	353	444
14	66	75	62	Insurance Companies	5.555	2.128	22.492	29.975	429	82951	82951	36	0	439
15	64.231, 64.232, 67	76	63,63	Investment Trusts & Fund Managers	32.174	21.191	245.784	299.158	1955	1128459	1117011	382	937	5839
16	72	80	76	Computer Services	1.714	2.795	13.231	17.742	354	254181	251098	95	15	1242
17	74.11	80	68	Legal Activities	9.162	0.112	40.078	85.557	1247	279970	277268	59	0	1028
18	74.12	80	68	Accountancy	11.125	1.581	34.927	85.013	1174	54540	53837	23	0	288
19	76, 77, 78 & 74.13 to 74.8	76,77,78	64,64,68	Other Business Activities	13.216	0.725	76.013	89.954	2176	968900	958203	179	0	3453
20	91,92	89,99	75,75	Other Services Activities	1.840	0.598	22.995	25.433	882	1902576	1886954	286	18365	8626
21	93	80	74	Recreation, Culture & Sport	9.526	6.103	27.135	42.766	888	1604743	1600810	63	2928	6102
22	94	83	70	Education	9.300	6.716	3.928	61.593	1508	1260709	1260709	8	2798	4869
23	95	84	71	Health, Social Work & Housing	29.981	9.555	118.711	158.231	3341	3757739	3755255	23	5624	13240
24	96-97	84-87	72	Public Services	8.837	4.609	13.131	26.579	573	15169331	15097454	3409	784	94941
25	79	81-82	69	Public Admin & Defence	2.661	10.012	44.372	57.050	1525	353807	353719	2	126	1058
PRODUCTION TOTALS					388.469	229.593	2476.230	3288.455	47111	173546378	156451664	804537	906428	1615602
Final consumers:														
Jersey Households					577.437	472.287	-	1059.202		128883141	125511644	143201	118367	544840
Tourists					202.418	36.358	-	239.347		9421447	9101875	13523	0	45451
Total					1168.324	738.237	2476.230	4587.005	47111	311850966	291065182	961262	1024795	2205893

Sector	Production Sectors:	Non-methane volatile organic compounds NMVOC (kg)	Carbon Monoxide CO (kg)	Nitrogen Dioxide N2O (kg)	Black smoke (kg)	Metals Feeds	Non-methane fuels	Kerosene LSK (kg)	Gas Oil (kg)	Light Fuel Oil (kg)	Heavy Fuel Oil (kg)	Coal (kg)	Mains & Bottled Gas (kg)
						Petrol/Diesel (kg)	Kerosene SKG (kg)						
1	Agriculture & Fishing	15089	65776	80.872	0	1063419	0	5839282	5839282	6487488	0	0	0
2	Quarrying & Construction	10341	28589	158.901	0	2002771	0	0	763731	0	0	0	16535
3	Total Manufacturing	12325	66780	50.629	0	724518	0	2716051	1263670	0	0	0	141581
4	Electricity	11072	43798	8.550	53852	143060	0	0	2724418	0	68170116	0	0
5	Water	1168	6829	3.327	0	50430	0	0	0	0	0	0	0
6	Gas and Oil & Fuel Distribution	4957	36919	19.998	0	286715	0	0	0	0	0	0	0
7	Jersey Telecommunications	876	4354	5.850	0	69439	0	0	6761	0	0	0	1804
8	Wholesale & Retail Trade	59443	349246	150.030	0	2383484	0	0	1059164	0	0	0	127006
9	Hotels, Restaurants & Catering	17050	96087	32.554	0	542560	0	0	6923828	0	50939	0	2385194
10	Land Transport	8931	52253	24.355	0	380541	0	0	81760	0	0	0	0
11	Sea & Air Transport and Transport Support	100305	294942	15.002	19575	221450	0	0	1552497	0	0	0	0
12	Post	256	649	4.206	0	52868	0	0	105528	0	0	0	0
13	Banks & Building Societies	115	692	0.084	0	2086	0	0	94014	0	0	0	12517
14	Insurance Companies	1298	8327	1.833	0	25814	0	0	0	0	0	0	0
15	Investment Trusts & Fund Managers	13933	89240	11.057	0	276425	0	0	222999	0	0	0	55844
16	Computer Services	3450	21946	3.541	0	78151	0	0	3542	0	0	0	0
17	Legal Activities	2161	15075	4.743	0	79045	0	0	0	0	0	0	39475
18	Accountancy	853	5475	0.679	0	16973	0	0	0	0	0	0	0
19	Other Business Activities	6615	39008	19.446	0	301149	0	0	0	0	0	0	0
20	Other Services Activities	10877	62370	30.993	0	479978	0	0	0	421223	0	0	1943
21	Recreation, Culture & Sport	2504	12858	8.426	0	123488	0	0	697034	0	0	0	694452
22	Education	465	752	3.220	0	40244	0	0	664837	0	288	0	639947
23	Health, Social Work & Housing	1473	2051	6.484	0	8185	0	0	1339827	0	0	0	2673004
24	Public Services	276336	1111528	0.904	0	11297	0	0	186432	0	0	0	1216855
25	Public Admin & Defence	153	170	0.145	0	1813	0	0	29955	0	0	0	366671
PRODUCTION TOTALS		561759	2403906	643	73427	9438772	0	1129384	25001059	8172382	68170116	51227	8562828
Final consumers:													
Jersey Households		1682956	9927995	1175.1	0	29376885	29290797	0	0	0	0	5409079	3988418
Tourists		158816	945345	114.8	0	2869444	0	0	0	0	0	0	0
Total		2403511	13277245	1933	73427	41685100	29290797	1129384	25001059	8172382	68170116	5460306	12351346

3.4 The NAMEA Accounts For Jersey In 1998

By adding the non-fuel combustion related emissions calculated in Section 3.3 (Tables 6.9 - 6.12) to the total emissions from fuel use in Table 6.8 I have calculated equations (6.1) and (6.2) to give total emissions of each pollutant by each sector and final demand group – see Table 6.13. (In Appendix 6A I provide more detailed tables giving emissions of each pollutant broken down by polluting sector and type of source.) Together with the fuel uses given in Table 6.1, Table 6.13 constitutes the base-year (1998) environmental accounts for the Jersey economy.

Note that in Table 6.13 I add an additional environmental variable, the Global Warming Potential (GWP) index. This is a composite environmental variable which indicates the global warming potential of any one activity by summing emissions of 3 of the greenhouse gases – CO₂, methane (CH₄) and N₂O – using weights (see Table 6.13) that reflect the global warming potential of each pollutant. I take the weights for individual pollutants entering the GWP Index to be those stated in the NAMEA dataset and UK Environmental Accounts (see, for example, National Statistics, 2001). These weights reflect measures of CO₂-equivalency and equal 1 for CO₂, 21 for CH₄ and 320 for N₂O.

The environmental accounts in Tables 6.1 and 6.13 and the economic (IO) accounts in Tables 5.3 and 5.4 combine to form a set of integrated economic-environmental accounts for Jersey in 1998. In Table 6.14 I show key data from each of these tables together in common physical (kg) and monetary (£ million) units using the same format as the UK adopts in its trial NAMEA accounts.

Table 6.14 permits some useful descriptive analysis of the environmental characteristics of individual sectors and final demand groups. For example we could examine the direct fuel use intensities of the production sectors by calculating the amount of each fuel type used in the production of £1million of total sectoral output or value-added, and/or the physical fuel requirements per monetary unit of intermediate inputs or per employee.

Similarly we could examine the direct pollution intensity of production in terms of pollution per monetary unit of output, value-added, intermediate inputs, and/or per employee.

However, as well as being useful in descriptive/accounting terms, these types of measurement of resource/pollution intensity can also be utilised for modelling purposes. In Sections 1 and 2.2 of this chapter I note that the second element of the environmental database requirements for the construction of an economic-environmental CGE modelling framework is environmental coefficients that will fix the relationship between economic activity and environmental variables. I now proceed to discuss the construction of an appropriate set of environmental coefficients for the economic-environmental model of Jersey.

4. Environmental Coefficients

In Section 2.2 I explain how the key difference in moving from constructing the economic database (Chapter 5) to constructing the environmental database for an economic-environmental CGE modelling framework is that it is necessary to specify how the environmental variables are related to economic ones. In this chapter I have stated what I assume to be the main economic-environmental relationships in equations (6.1) and (6.2) in order to estimate (account for) base year pollution levels using physical fuel-use data and combustion and non-combustion emissions factors identified for the target economy of Jersey. However, equations (6.1) and (6.2) could also be used to fix the relationship between economic activity and environmental variables for modelling purposes in the manner proposed by Beauséjour *et al* (1994, 1995) and Bergman (1990, 1991). In Chapter 4 I discuss how the approach to modelling pollution generation adopted in the Beauséjour *et al* (1994, 1995) and Bergman (1990, 1991) models would appear to be the most comprehensive of those examined in this study because it encompasses both fuel-combustion-related and non-combustion-(process)-related emissions generation. Equations (6.1) and (6.2) would be suitable for this

purpose because they contain the environmental coefficients necessary to model both of these elements:

- The **fuel use input-pollution coefficients** (emissions factors), e_{ijt}^k and e_{zjt}^k , for each type of fuel, j , and fuel combustion technology, t , for each production sector, i , and final demand sector, z , for each pollutant, k .
- The **process output-pollution coefficients**, n_i^k and n_z^k , for each (non-fuel-combustion) polluting process inherent in the activities of each production sector, i , and final demand sector, z , for each pollutant, k .

Modelling pollution using equations (6.1) and (6.2) would therefore allow me to model changes in pollution levels due to the ‘composition’, ‘technology’, ‘input substitution’ and ‘scale’ effects that I discuss in Chapter 4 (Section 5.2)²¹.

Alternatively, if ‘input substitution’ effects are not considered to be important in the target economy – i.e. if possibilities for changing pollution levels by substituting between different types of intermediate (material or energy) inputs are limited – equations (6.1) and (6.2) can be used to construct more basic ‘Leontief’ output-pollution coefficients. These relate *all* pollution generation solely to outputs, and their use implies the assumption that the intermediate input mix does not change or that, if it does, this will not affect the level of emissions generated. This means that only changes in pollution due to changes in the composition and/or scale of aggregate output in the economy are modelled.

²¹ To remind the reader, I define the ‘composition’, ‘technology’, ‘input substitution’ and ‘scale’ effects in Chapter 4 (Section 5.2) as follows:

- (1) *Composition effect* – change in pollution induced by a change in the commodity composition of aggregate production (goods with a higher/lower embodied pollution content)
- (2) *Technology effect* – evolving cleaner technologies, independent of the input mix used
- (3) *Input substitution* – changing the input mix towards ‘cleaner’ types of input
- (4) *Scale effect* – increase/decrease in pollution attributable to an increase in aggregate economic activity

I introduce Leontief output-pollution coefficients in Chapter 3 (Section 4.3) as a component in the environmental IO system proposed in Leontief (1970) and introduced empirically in Leontief & Ford (1970). Basically a set of Leontief output-pollution coefficients relate the direct generation of emissions of each pollutant, k , to the gross outputs of each sector, i , of the economy. In other words, the standard Leontief assumption of a constant linear relationship between the use of inputs and the production of output is carried over from the standard IO framework to the environment. This means that even in the case of CGE modelling, where the Leontief assumption of fixed production coefficients can be relaxed, the assumption is imposed that each unit (in monetary terms) of sectoral output is accompanied by a constant amount of each pollutant (in physical terms). This implies a K by I matrix ($\mathbf{M}_i$) of output-pollution coefficients, with a row of coefficients for each pollutant, k , across each sector, i , of the economy. The elements of the output-pollution coefficients matrix, $\mathbf{M}_i$, can be defined as

$$(6.3a) \quad m_{k,i} = P_{k,i}/X_i, \quad \forall i = 1, \dots, I, \quad \forall k = 1, \dots, K$$

Substituting equation (6.1) into (6.3a) for $P_{k,i}$, this means that the output-pollution coefficients take the form:

$$(6.3b) \quad m_{k,i} = [\sum_{j,t} (e_{ijt}^k \cdot F_{ijt}) + n_i^k \cdot X_i] / X_i$$

This can be simplified to

$$(6.3c) \quad m_{k,i} = \sum_{j,t} (e_{ijt}^k \cdot f_{ijt}) + n_i^k$$

where $f_{ijt} = F_{ijt}/X_i$.

Leontief (1970) and Leontief & Ford (1972) limit their attention to direct emissions generation in the production sectors of the economy. However, in Chapter 3 (Section 5.4) I explain that a crucial development of the Leontief framework in environmental IO models such as those of Gale (1995), Lenzen (1998), Weir (1998) and Hawdon & Pearson (1995) is the inclusion of direct emissions generation by final demand sectors. If final demand sectors are responsible for the direct generation of any emissions (by combustion of fossil fuels, mainly during heating or transport activities) another matrix of coefficients for emissions of each pollutant by these groups can be constructed. In Section 3 I show that the direct emissions generated by households and tourists is an important element of total pollution generation in Jersey (see Table 6.13). Therefore, inclusion of direct emissions coefficients for these elements of final demand is a crucial element in the Jersey economic-environmental modelling framework.

For Z final demand sectors the emissions coefficients will express the physical amount of emissions per unit (£1million) of *final demand expenditure* (c) in the chosen base-year. Thus there is also a K by Z matrix (which I refer to as $\mathbf{M}_z$) of expenditure-pollution coefficients, with a row of coefficients for each pollutant, k , across each final demand sector, z (final demand groups are identified by the subscript 'z' (where $z = 1, \dots, Z$)). The elements of the final demand expenditure-pollution coefficients matrix, $\mathbf{M}_z$, are defined as

$$(6.4a) \quad m_{k,z} = P_{k,z}/C_z, \quad \forall z = 1, \dots, Z, \quad \forall k = 1, \dots, K$$

Substituting equation (6.2) into (6.4a) for $(p_x)_{k,z}$, this means that the final demand expenditure-pollution coefficients take the form:

$$(6.4b) \quad m_{k,z} = [\sum_{j,t} (e^k_{zjt} \cdot F_{zjt}) + n^k_z \cdot C_z]/C_z$$

which simplifies to

$$(6.4c) \quad m_{k,z} = \sum_{j,t} (e^k_{zjt} \cdot f_{zjt}) + n^k_z$$

where $f_{zjt} = F_{zjt}/C_z$.

Just as with output-pollution coefficients in the production sectors, use of final demand expenditure-pollution coefficients in a CGE framework means imposing the assumption that the composition of final demand expenditure by sector z does not change or that, if it does, this will not affect the level of emissions generated. That is to say, only changes in pollution due to changes in the composition and/or scale of aggregate final demand expenditure can be modelled; 'technology' effects and 'input substitution' effects due to changes in the composition of final demand expenditure by any one sector, z , will not be captured. (In an environmental IO system, or if a Leontief relationship is assumed to exist in the choice between individual consumption goods, this will be a consistent assumption.)

Use of basic Leontief output-pollution and final demand expenditure-pollution coefficients may also be the most practical option if, as is the case in the present study, resource constraints preclude development of modelling software to allow input-pollution relationships to be modelled using the relationships stated in (6.1) and (6.2). The software that is available to me requires significant programming input to allow us to model substitutability between different types of intermediate inputs (including different fuel types) and the relationship between input use and pollution generation. Not only would I have to adapt the current CGE modelling programme to relate pollution generation to input-use, but I would also have to restructure the intermediate production block for each sector, separating different energy/fuel types and other material inputs. I discuss this problem in more detail in Chapters 8 and 9, where I reach the stage of specifying and using the full economic-environmental CGE model for Jersey. For now it is sufficient to state that the sparsity of the intermediates matrix (as shown by the top left hand quadrant of the IO table shown in Table 5.3) precludes the specification of anything other than Leontief technology between locally produced intermediate inputs. Input substitution in production is only possible:

- (a) between foreign and domestically produced goods (for each intermediate commodity defined by the local production sector i)
- (b) between labour and capital
- (c) between total value-added (a CES combination of labour and capital) and a composite intermediate input (a Leontief combination of domestic or foreign intermediate inputs)

Any reduction (increase) in pollution levels resulting from a substitution away from (toward) locally produced inputs by either (a), (b) or (c) will be the only input substitution pollution effects that could be captured using the basic Leontief direct emissions coefficients and available modelling software.

Thus, while I do identify a full set of Jersey-specific fuel use input-pollution coefficients and process output-pollution coefficients in this chapter (Section 3), the economic-environmental CGE modelling framework that I am constructing for the case of Jersey must rely on a set of more restrictive Leontief pollution coefficients.

I present the Jersey-specific matrices $\mathbf{M}_i$ and $\mathbf{M}_z$ in Table 6.15. $\mathbf{M}_i$ is a 9 (rows) by 25 (columns) matrix showing direct emissions of each of the 8 individual pollutants and one composite (GWP) pollutant generated by the 25 production sectors. $\mathbf{M}_z$ is a 9 by 6 matrix showing direct emissions of each pollutant by the six final demand groups that are responsible for the direct generation of emissions during production/consumption activities in Jersey. I also present a single vector, $\mathbf{m}_h$ of expenditure-pollution coefficients for households as an aggregate final demand group: if households are treated as an aggregate group this vector will be used in a 9x2 version of $\mathbf{M}_z$ along with the vector of tourist expenditure coefficients, $\mathbf{m}_t$. The output- (expenditure-) pollution coefficients are all stated in terms of kilograms of emissions per £1million of total sectoral output or final demand expenditure, except in the case of the composite GWP index, where I state the value of the index per £1million output/expenditure.

Table 6.15 Direct Emissions (kilograms) Per £1million Domestic Gross Output/Expenditure By Production Sector/Final Demand Group In Jersey 1998

(The matrices M₁ and M₂ of Jersey-specific output- and expenditure-pollution coefficients)

Sectors	Agriculture & Fishing	Quarrying & Construction	Manufacturing	Electricity	Water	Gas, Oil & Fuel Dist.	Jersey Telecom.	Wholesale & Retail Trade	Hotels, Rest. & Catering	Land Transport	Sea & Air Trans. & Trans Supp	Jersey Post	Banks & Building Soc.	Insurance Companies	Inv. Trusts & Fund Mgrs	Computer Services	Legal Activities
Pollutants																	
Global warming potential (GWP) composite	556785.321	31081.142	58294.542	1310923.410	12998.454	81994.473	5420.443	24878.513	43792.986	63615.886	278655.241	14050.869	79.938	2767.332	3772.120	14326.664	3272.336
Carbon dioxide (CO ₂) as carbon	262119.383	30841.215	58068.420	1310789.948	12864.400	61379.526	5372.080	24447.248	43706.384	62988.274	278157.957	13973.350	79.859	2731.696	3733.851	14152.851	3240.758
Methane (CH ₄)	14010.885	1.168	3.328	3.652	2.563	9.434	0.551	4.718	1.978	12.205	20.518	0.342	0.003	1.188	1.277	5.331	0.685
Sulphur dioxide (SO ₂)	5419.748	14.026	662.047	9500.401	0.000	0.000	0.667	12.643	134.556	16.888	260.831	23.915	0.314	0.000	3.131	0.838	0.000
Nitrous oxides (NO _x)	2244.175	102.768	339.256	17312.425	62.762	450.462	17.067	166.764	212.416	392.770	5105.394	48.679	0.396	14.632	19.517	69.997	12.016
Non-methane volatile organic compounds (NMVOC)	265.854	45.217	122.696	237.174	93.034	333.294	20.595	168.947	76.119	439.210	1432.355	13.822	0.102	43.282	46.575	194.463	25.256
Carbon monoxide (CO)	1158.911	125.007	664.799	938.178	547.545	1809.987	107.040	992.616	428.973	2569.731	4211.767	35.044	0.617	277.786	298.303	1236.975	152.822
Nitrogen dioxide (N ₂ O)	1.411	0.695	0.504	0.183	0.259	1.345	0.119	0.426	0.145	1.198	0.214	0.227	0.000	0.034	0.037	0.200	0.055
Black smoke	0.000	0.000	0.000	1153.552	0.000	0.000	0.000	0.000	0.000	0.000	279.530	0.000	0.000	0.000	0.000	0.000	0.000

Sectors	Accountancy	Other Bus. Activities	Other Service Activities	Recreation, Culture & Sport	Education	Health, Social Work & Housing	Public Services	Public Admin. & Defence
Pollutants								
Global warming potential (GWP) composite	641.543	10761.091	74806.861	37523.612	20487.249	23748.390	570736.347	6201.739
Carbon dioxide (CO ₂) as carbon	633.282	10652.176	74192.623	37431.643	20468.375	23732.688	568032.035	6200.202
Methane (CH ₄)	0.276	1.995	11.261	1.471	0.127	0.143	128.275	0.036
Sulphur dioxide (SO ₂)	0.000	0.000	722.102	68.455	45.432	35.542	29.492	2.205
Nitrous oxides (NO _x)	3.392	38.391	339.165	142.684	79.049	83.676	3572.079	18.540
Non-methane volatile organic compounds (NMVOC)	10.036	73.534	415.864	58.559	7.549	9.311	10396.976	2.686
Carbon monoxide (CO)	64.398	433.554	2452.315	300.661	12.216	12.961	41820.539	2.986
Nitrogen dioxide (N ₂ O)	0.008	0.216	1.219	0.197	0.052	0.041	0.034	0.003
Black smoke	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Household 1	Household 2	Household 3	Household 4	Household 5	Tourists	Aggregate Households
118611.722	147369.062	126696.385	117887.989	112946.321	39363.075	121679.442
112638.528	142900.420	123172.748	115038.621	110763.415	38027.894	118496.388
270.678	192.075	149.608	118.830	89.841	56.501	135.197
206.566	139.489	194.584	105.548	43.927	0.000	111.751
464.288	633.203	549.743	512.293	464.589	188.895	514.388
1389.401	2008.861	1797.617	1626.962	1343.318	663.537	1588.890
8117.861	11854.932	10562.632	9602.243	7957.271	3949.677	9373.087
0.932	1.403	1.232	1.139	0.956	0.480	1.109
0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 6.16 Direct Energy/Fuel Use (kilograms) Per £1million Domestic Gross Output/Expenditure By Production Sector/Final demand group In Jersey 1998

(The matrices E₁ and E₂ of Jersey-specific output- and expenditure-energy use coefficients)

Sectors	Agriculture & Fishing	Quarrying & Construction	Manufacturing	Electricity	Water	Gas, Oil & Fuel Dist.	Jersey Telecom.	Wholesale & Retail Trade	Hotels, Rest. & Catering	Land Transport	Sea & Air Trans. & Trans Supp	Jersey Post	Banks & Building Soc.	Insurance Companies	Inv. Trusts & Fund Mgrs	Computer Services	Legal Activities
Petrol/diesel	18736.558	8757.234	7212.638	3064.456	4043.374	19278.097	1632.174	6774.265	2422.227	18714.603	3162.298	2852.603	1.858	861.190	924.010	4404.919	923.890
Kerosene SQK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kerosene L&K	19898.799	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gas Oil	102883.241	3339.457	27038.519	58359.143	0.000	0.000	158.924	3010.323	30910.998	4020.879	22169.612	5694.007	74.868	0.000	745.422	199.642	0.000
Light Fuel Oil	114304.094	0.000	12579.945	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heavy Fuel Oil	0.000	0.000	0.000	1460256.703	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	227.415	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gas (Maine & Bottled Propane/Butane)	0.000	72.302	1409.448	0.000	0.000	0.000	42.393	380.972	10648.549	0.000	0.000	0.000	11.154	0.000	186.671	0.000	344.507

Sectors	Accountancy	Other Bus. Activities	Other Service Activities	Recreation, Culture & Sport	Education	Health, Social Work & Housing	Public Services	Public Admin. & Defence
Pollutants								
Petrol/diesel	199.647	3347.816	18872.110	2887.501	653.391	512.255	425.053	31.783
Kerosene SQK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kerosene L&K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gas Oil	0.000	0.000	0.000	16298.703	10794.033	8462.468	7021.892	525.082
Light Fuel Oil	0.000	0.000	16561.967	0.000	0.000	0.000	0.000	0.000
Heavy Fuel Oil	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coal	0.000	0.000	0.000	0.000	4.678	0.000	0.000	0.000
Gas (Maine & Bottled Propane/Butane)	0.000	0.000	76.381	16238.339	10389.923	16893.014	45783.406	6427.232

Household 1	Household 2	Household 3	Household 4	Household 5	Tourists	Aggregate Households
23302.465	35086.674	30795.330	28463.093	23891.417	11988.617	27734.915
31305.801	28108.196	19179.411	19780.386	36520.515	0.000	27653.639
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000
9630.017	8435.939	9170.596	4884.226	1760.893	0.000	5106.748
6043.804	3531.022	3193.026	5070.784	2749.718	0.000	3765.492

I report an additional set of environmental coefficients in Table 6.16. Another interesting question is the relative energy/fuel intensity of different types of activity and the impact on energy consumption of any disturbance to the system. The pollution coefficients do of course reflect energy/fuel intensities; however, it may be desirable in some circumstances to focus on energy consumption itself. If I could model equations (6.1) and (6.2) in the Jersey economic-environmental CGE framework, physical energy consumption results would be generated automatically. However, the aforementioned constraints on model development in the current study mean that while physical energy consumption provides the basis for the construction of matrices $\mathbf{M}_i$ and $\mathbf{M}_z$, it is not actually included as a variable(s) in the environmental component of the model. (Intermediate and final consumption of the outputs of the energy supply sectors is captured in the economic component of the model. However, differences in unit costs to different users and the aggregation of different fuel types in the monetary measurement of sectoral outputs mean that physical consumption of each fuel individual type is not.)

Therefore, I construct the additional matrices $\mathbf{E}_i$ and $\mathbf{E}_z$ of energy/fuel use intensities. $\mathbf{E}_i$ is a $J \times I$ matrix of coefficients denoting the amount (kilograms) of energy/fuel j used in the production of one unit (£1million) of output by sector i , with a row of coefficients for each energy/fuel type, j , across each production sector, i , of the economy. The elements of matrix, $\mathbf{E}_i$, are defined as

$$(6.5) \quad f_{i,j} = \sum_t F_{i,j,t} / X_i, \quad \forall i = 1, \dots, I, \forall j = 1, \dots, J, \forall t = 1, \dots, T$$

Similarly $\mathbf{E}_z$ is a $J \times Z$ matrix of coefficients denoting the amount (kilograms) of energy/fuel j used per £1million total expenditure by final demand sector z , with a row of coefficients for each energy/fuel type, j , across each final demand sector, z , of the economy. The elements of matrix $\mathbf{E}_z$ are defined as

$$(6.6) \quad f_{ij} = \sum_i F_{ij} / C_z, \quad \forall z = 1, \dots, Z, \quad \forall j = 1, \dots, J, \quad \forall t = 1, \dots, T$$

In other words, the matrices E_i and E_z shown in Table 6.16 give the direct energy intensities of each production and final demand activity in Jersey (in 1998). With 8 individual fuel types distributed by the 'Oil, Gas & Fuel Distribution' sector E_i is an 8x25 matrix²². Note that in Table 6.16 I also include a vector of energy use intensities for the aggregate household sector. As with the pollution coefficients matrix M_z , E_z is an 8x6 matrix where the household sector is disaggregated by income band, but an 8x2 matrix if households are treated as a single category of final demand.

Together, then, along with the base year environmental accounts that I have constructed in Section 3, the matrices M_i , M_z , E_i and E_z in Tables 6.15 and 6.16 form the environmental component of the economic-environmental CGE model of Jersey.

5. The Added Precision From Estimating And Using Jersey-Specific Data For Economic-environmental Analysis

5.1 The Use Of National Technical Coefficients For Regional Economies

The availability of the very rich database that I have used here to generate a very detailed set of economic-environmental accounts (Section 3) and coefficients (Section 4) for Jersey gives me the opportunity to explore a specific example of what is a widely discussed problem in regional accounting and modelling. This is the issue of the appropriateness of region-specific data collection and modelling. Because of the

²² Seven fuel/energy types are distributed by the Jersey 'Gas, Oil & Fuel Distribution' sector. In Section 3 I identify these as automotive fuel (petrol/derv), kerosene (SGK), kerosene (LSK), gas oil, light fuel oil, coal and gas. The 'Electricity' sector imports heavy fuel oil for generation. Ideally the physical use of electricity as a ninth energy type should also be included in matrices E_i and E_z . However information is not available on the physical use of electricity by different users. The IO table (Table 5.3), which separately identifies the 'Electricity' sector provides information on the value of electricity output purchased by different users, but data were not available on unit costs to different users to allow me to convert this into physical units. Therefore for now in modelling applications I take the change in total

resource costs involved in constructing regional economic accounts in the form of IO tables using primary region-specific data, it is common practice to attempt to derive regional tables from national tables. This involves adjusting national (input-output) technical coefficients to reflect differences in the size and composition of activity at the regional level (e.g. employment, import requirements, degree of specialisation etc – see Isserman (1980), Round (1983), Richardson (1985) and Flegg *et al* (1995) for reviews of adjustment methods). Several studies have been undertaken to assess the accuracy of deriving regional economic IO accounts in this manner (where actual region-specific tables are available for comparison - see for example, Jensen & West (1980) and Harrigan *et al* (1980a and 1980b)).

This debate relates mainly to the question of region-specificity in standard economic accounting and modelling. However, all the same issues are relevant in the case of economic-environmental analysis. Indeed the appropriateness of using region-specific data is one of the core questions that has arisen in the consultation process instigated by the UK Environment Agency, the English Regional Development Agencies (RDAs) and the National Assembly for Wales on developing environmental accounts and models for use at the regional level. The Scottish Executive has recently set up the Scottish Environmental Accounts Working Group (SEAWG) to explore the possibility of region-specific environmental accounting and modelling in Scotland. (I discuss both these projects in Chapter 1, Section 1.)

Where region-specific data for technical coefficients representing economic-environmental relationships are not available, the main criteria in using national coefficients is whether the polluting technology and consumption (mainly fuel use) patterns that determine pollution generation are likely to be similar for equivalent activities at the regional and national level. In the case of Jersey, the most suitable

electricity consumption to be the change in the value of total output in the 'Electricity' sector. This, however, is not ideal and I hope to get better physical data for electricity use in Jersey in the future.

national economy from which to draw data is the UK²³. Therefore, in this section I use the Jersey economic-environmental database generated above to identify and assess the added precision gained from estimating Jersey-specific environmental coefficients (physical energy-use and pollution intensities) as compared to those that can be derived from UK data. This exercise also allows an indirect test of whether the Jersey regional economy is similar to that of the UK in terms of its key structural characteristics, and therefore of the value gained from the type of region-specific accounting, modelling and policy analysis that I am undertaking here.

In Appendix 6B to this chapter I detail how a set of pollution coefficients for the UK for the chosen base year of 1998 are constructed in the manner described by the equations (6.3a) and (6.4a) using the 1998 UK (trial) NAMEA accounts. The UK NAMEA accounts for 1998 provide data on total emissions of $K=18$ individual pollutants for $I=76$ production sectors and $Z=1$ final demand sector (aggregate households). Therefore I construct a 18×76 matrix, M_i^{UK} , of output-pollution coefficients with elements

$$(6.7) \quad m_{k,i}^{UK} = P_{k,i}^{UK} / X_i^{UK}, \quad \forall i = 1, \dots, I, \quad \forall k = 1, \dots, K$$

Similarly, in Appendix 6A, I define a matrix of final demand expenditure-pollution coefficients, M_z^{UK} , can be defined with elements:

$$(6.8) \quad m_{k,z}^{UK} = P_{k,z}^{UK} / C_z^{UK}, \quad \forall z = 1, \dots, Z, \quad \forall k = 1, \dots, K$$

Because the UK NAMEA data only record emissions data for one final demand sector, households ($z = h$), M_z^{UK} effectively collapses to an 18×1 vector of household final expenditure-pollution coefficients, $\mathbf{m}_h^{UK}$.

²³ See Footnote 1 of this Chapter.

I have to aggregate the matrix $\mathbf{M}_i^{\text{UK}}$ to make it consistent with the sectoral breakdown of the Jersey accounting system. In Appendix 6B I explain how this is done using a weighting system that reflects the composition of total and sectoral output in Jersey, to give the (18x25 UK-adjusted matrix, $\mathbf{M}_i^{\text{UK}(\theta)}$ of UK-adjusted output-pollution coefficients for Jersey (1998). The matrix $\mathbf{M}_z^{\text{UK}(\theta)}$ of UK-adjusted final demand expenditure-pollution coefficients is the same as $\mathbf{M}_z^{\text{UK}}$, with no adjustment required to the single positive vector, $\mathbf{m}_h^{\text{UK}}$, of household coefficients. These are reported in Table 6B.4 in Appendix 6B for a sub-set of (seven) pollutants that I also report in the Jersey-specific matrices, $\mathbf{M}_i$ and $\mathbf{M}_z$.

I should highlight one important point. In Section 4 I explain that the Jersey-specific pollution coefficients actually take the form of equations (6.3b) and (6.4b), with $P_{k,i}$ and $P_{k,z}$ having been determined for Jersey (in 1998) by estimating (6.1) and (6.2) for each production and final demand sector. However, while staff at the Environmental Accounts Branch of the ONS confirm that in principle the UK method of estimating sectoral emissions is consistent with my equations (6.1) and (6.2), they acknowledge that in practice a number of adjustments are made. However these are not specified and a full account of the methodology used to estimate the sectoral emissions levels reported in the UK NAMEA accounts is not supplied. In particular, while the UK NAMEA accounts do report the total amount of each type of fuel used by each production and final demand sector, these are not disaggregated by technology to give the F_{ijt} and F_{zjt} required for estimating (6.1) and (6.2). Moreover, no information is given on the emissions factors, e_{ijt}^k , e_{zjt}^k , n_i^k and n_z^k . The implication of all this is that it is not possible to specify the UK coefficients in any more detail than is given in (6.7) and (6.8).

Therefore, for the application of matrices $\mathbf{M}_i^{\text{UK}(\theta)}$ and $\mathbf{M}_z^{\text{UK}(\theta)}$ to give accurate figures for Jersey pollution generation, two assumptions generally have to hold:

(a) *The fuel intensity of production does not vary between the UK and Jersey economies.* That is to say, the elements f_{ijt} and f_{zjt} on the right-hand side of equations (6.3c) and (6.4c) respectively do not vary between the UK and Jersey economies.

(b) *Polluting technology does not vary between the UK and Jersey economies.* That is to say, the emissions factors, e_{ijt}^k , e_{zjt}^k , n_i^k and n_z^k are the same across the UK and Jersey.

These assumptions are implicit in the use of the UK-adjusted pollution coefficients and, therefore the accuracy of the base-year data set constructed using them and any subsequent analysis will be dependent on their validity.

Note, however, that if better national data were available it would be possible to derive a set of UK-adjusted coefficients that rely on a weaker set of assumptions. Jersey-specific data are available on Jersey-specific fuel use (reported above in Table 6.1) and total output/expenditure by sector (Tables 5.3 and Table 5.4) - i.e. the F_{ijt} , F_{zjt} , x_i and c_z . Therefore, if information were provided on the UK emissions factors, e_{ijt}^k , e_{zjt}^k , n_i^k and n_z^k , it would be possible to use (6.1) and (6.2) to derive versions of $M_i^{UK(\theta)}$ and $M_z^{UK(\theta)}$ that only rely on assumption (b). That is to say, I would only need to assume common technologies across the two economies.

However, the only other information included in the UK NAMEA tables is the amount of fuel used by each production sector and households in 1998. In Section 4 I derive the Jersey-specific matrices, E_i and E_z , of energy/fuel use intensities for each production and final demand sector using equations (6.5) and (6.6). This involves dividing the total physical quantity of each type of fuel, j , used by each production sector i and final demand sector z in 1998 by the total output/expenditure of that sector. I take the Jersey-specific fuel-use figures, $F_{j,i}$ and $F_{j,z}$ (aggregating across all technologies) from the NAMEA accounts shown in Table 6.14 and the gross sectoral outputs/total final demand expenditures (x_i and c_z) from the IO table (Tables 5.3 and 5.4). For the UK, I can derive

an equivalent set of energy/fuel use intensities using the 76-sector fuel-use, sectoral output and final demand expenditure figures in the UK 1998 trial NAMEA table. I then adapt to the Jersey case in the same manner explained for derivation of the UK-adjusted pollution coefficients in Appendix 6B (using weights that reflect the composition of output at the aggregate and sectoral levels in the Jersey economy). The resulting matrices, $E_i^{UK(\theta)}$ and $E_z^{UK(\theta)}$, can be used for accounting for energy use in Jersey, just as matrices $M_i^{UK(\theta)}$ and $M_z^{UK(\theta)}$ can be used to estimate total emissions²⁴. Here, in Section 5.3 below, I use them to assess the validity of assumption (a) for the case of Jersey.

5.2 Comparison Of Results Using Jersey-Specific And UK-Adjusted Environmental Coefficients

5.2.1 Coverage

If we compare the UK-adjusted coefficients (matrices $M_i^{UK(\theta)}$ and $M_z^{UK(\theta)}$) in Table 6B.4 with the Jersey-specific ones (M_i and M_z) in Table 6.15 it is clear that in general the two sets differ quite significantly. The two sets have seven individual pollutants in common and I limit the present discussion to a comparison of these across the two sets (coverage in both cases is determined by data availability, rather than some decision on my part as to what pollutants are appropriate for inclusion).

One thing that is immediately clear is that in the UK-adjusted set there are no coefficients for the tourist final demand sector or for households disaggregated by income. This is due to the absence of data on emissions by these groups. As I explain in Section 3, the Jersey-specific data separately identifies direct emissions generation by tourists during their stay on the Island. This allows me to derive a separate vector of pollution coefficients for tourists in the Jersey-specific matrix, M_z . On the other hand, the UK sectoral emissions data used to generate the UK-adjusted coefficients do not

²⁴ Note that, as with the UK-adjusted pollution coefficients, the absence of data on direct fuel use by tourists means that it is not possible to include a vector of fuel intensities for $z = \text{tourists}$ in matrix $E_z^{UK(\theta)}$.

separately identify pollution directly generated by tourists (nor do the UK energy use data include automotive fuel use by tourists). It is likely that any emissions by tourists in the UK dataset are included in the figures given for domestic (UK household) pollution generation. However there is no documented information to support this supposition so I take the omission of tourist expenditure as a polluting activity in the UK database to mean that no direct emissions by tourists are accounted for. If the household emissions figures do include emissions by tourists this will upwardly bias the UK-adjusted household direct emissions coefficients and result in an omission and/or misallocation of some direct emissions generation in Jersey.

The Jersey-specific data also provide information on household energy use and other polluting activities disaggregated by income, which allows me to estimate five separate vectors of household emissions coefficients in matrix $\mathbf{M}_z$. The absence of UK-adjusted versions of these coefficients limits the scope of potential analyses. In the Jersey-specific set of coefficients in Table 6.15, it is clear that emissions intensities vary with household income, which suggests a potential need for distributional analysis of any related policy change or other disturbance. However, the presence of a vector of pollution coefficients for aggregate households does mean that, in contrast to the case of tourists, it is possible to account for direct emissions generation in household consumption using the UK-adjusted coefficients. Nonetheless, if emissions by tourists are indeed included in the UK household data, direct emissions generation by households will be over-estimated.

Therefore, my first conclusion is that in the case of Jersey fuller data are available at the regional level. It might be expected that in general better data will be available at the national level due to what are likely to be significant economies of scale in data collection. In particular, it would be expected that greater access to professional data collection and statistical analysis, and larger survey samples would lead to the availability of superior data at the national level. However, the converse appears to be true in the comparison of Jersey and the UK, where the national data appears to be *inferior*, at least in terms of scope. Moreover, the UK data also seem to be inferior in

terms of transparency, as reflected in the fact that it is not clear *how* the $P_{k,i}^{UK}$ and $P_{k,z}^{UK}$ reported in the UK NAMEA tables have actually been derived (see Section 5.1 above), or whether tourist emissions are included in the household figures.

The superiority of the Jersey data in terms of scope is likely to be explained by the level of resources that have been invested in comprehensive primary data collection in Jersey, which is not limited to the data collection process for the model construction being undertaken here. For example, data on household and tourist expenditure on different types of fuel have been collected as part of the more general surveys conducted by the States of Jersey that I use in the construction of the Jersey IO table for 1998 (see Chapter 5, Section 3.1). In terms of the environmental question in particular, the ongoing investment by States of Jersey in the study and quantification of the nature of pollution problems in the economy is especially significant (even more so if it is assessed in terms of spending per capita of population). This is illustrated by the existence of a number of reports commissioned over recent years on different aspects of pollution generation and Jersey's continued involvement in studies on energy use and pollution problems as part of the South West Energy and Environment Group²⁵. Furthermore, Jersey's small island status and the structure of the energy supply industries allow very accurate data collection on different types of energy imported and supplied to different users in the economy. This emphasises the fact that data collection at the regional level is more likely to reflect region-specific needs and policy concerns.

5.2.2 Relative And Absolute Values

I now turn my attention to the estimated values for the pollution coefficients derived using Jersey-specific and UK-adjusted data in Tables 6.15 and 6B.4 respectively. The composition of the 25 production sectors is equivalent across both sets of coefficients,

²⁵ As noted above, the South West Energy and Environment Group (SWEEG) is an alliance of local authorities in the South West region of England and the States of Jersey. The SWEEG funds ongoing studies into energy and pollution issues (orientated to the needs of the SWEEG participants) at the Centre for Energy and the Environment at Exeter University.

which means that I can directly compare the emissions intensities shown for each sector and aggregate households in Tables 6.15 and 6B.4. For the pollutants that are common to both sets, two observations can be made:

1. The Jersey-specific and UK-adjusted coefficients for any one sector differ significantly in terms of the *absolute pollution intensities* of production/consumption (i.e. the level of emissions per unit of output/expenditure).
2. Overall, the sets of Jersey-specific and UK-adjusted coefficients differ significantly in terms of the *relative pollution intensities* of the different activities in the Jersey economy.

Both of these factors are crucial. If the absolute intensities are over- or under-stated this will lead to errors in estimating total pollution in the Jersey economy. If the relative intensities are incorrect this will lead to errors in determining the direct (*and* indirect²⁶) contributions of different production sectors and consumption activities to the pollution problem. As well as affecting the accuracy of the base-year environmental accounts, I would expect both these factors to impact on estimates of both the magnitude and composition of the environmental impacts of any disturbance that I may go on to simulate using the Jersey economic-environmental model.

I can determine the magnitude of the first problem (the differences in the absolute level of the pollution intensities across all sectors) by looking at the total pollution estimates that the two sets of coefficients would provide for the Jersey economy.

I estimate the $(k \times 1)$ vector, $\mathbf{P}$, of pollution generated in Jersey²⁷ as

²⁶ See Chapter 7 and Appendix 7B.

²⁷ Note that with the Jersey-specific pollution coefficient matrices, $\mathbf{M}_i$ and $\mathbf{M}_z$, (6.9) is an identity. That is to say, I am simply recreating the base-year vector of total emissions, $\mathbf{P}$, estimated in Section 3 of this chapter using the 1998 fuel use and emissions factor data and equations (6.1) and (6.2) (see the bottom row of Table 6.13).

$$(6.9) \quad \mathbf{P} = \mathbf{P}_i + \mathbf{P}_z = \mathbf{M}_i \cdot \mathbf{X} + \mathbf{M}_z \cdot \mathbf{C}^T$$

where $\mathbf{X}$ is the (ix1) vector of sectoral outputs (with elements X_i) and $\mathbf{C}^T$ is the (zx1) transpose of the vector of total final demand expenditures (with elements C_z) by Jersey households and tourists in the Jersey IO tables (Tables 5.3 and 5.4).

I can also estimate a vector of total emissions in Jersey, $\mathbf{P}^{(\text{UK})\theta}$, using the UK-adjusted matrices $\mathbf{M}_i^{\text{UK}(\theta)}$ and $\mathbf{M}_z^{\text{UK}(\theta)}$ of pollution coefficients in place of the Jersey-specific matrices $\mathbf{M}_i$ and $\mathbf{M}_z$ (noting that in the latter the column entries for z = tourists are all zeros due to the absence of UK-adjusted pollution coefficients for tourists):

$$(6.10) \quad \mathbf{P}^{(\text{UK})\theta} = \mathbf{P}_i^{(\text{UK})\theta} + \mathbf{P}_z^{(\text{UK})\theta} = (\mathbf{M}_i)^{\text{UK}(\theta)} \cdot \mathbf{X} + (\mathbf{M}_z)^{\text{UK}(\theta)} \cdot \mathbf{C}^T$$

I report the results of calculating (6.9) and (6.10) in Table 6.17. These show that there are differences between the total emissions estimates derived using the set of Jersey-specific coefficients and those estimated using the UK-adjusted set. In the case of five out of seven of the pollutants, the UK-adjusted coefficients give estimates that are much larger than the values obtained from the Jersey-specific measures. I find the largest difference in the case of N_2O , where the estimate of total emissions using the UK-adjusted coefficients is more than 153 times the size of the estimate based on the Jersey-specific fuel-use figures and emissions factors. This is an extreme result, and one that is likely, at least in part, to reflect the omission of N_2O emissions from fertiliser use in the Agriculture & Fishing sector in the Jersey-specific environmental accounts (see Section 3.3.4 above). I find the next biggest difference in the case of methane, where the UK-adjusted estimate is 507% higher than the Jersey-specific one (followed by 175% for CO_2 , 135% for SO_2 , and 43% for NO_x). In the case of the two remaining pollutants, NMVOC and carbon monoxide (CO), I find that the Jersey-specific estimates of total emissions are higher than the UK-adjusted ones (the UK-adjusted estimates being respectively 20% and 35% less than the Jersey-specific ones).

Table 6.17 Environmental IO Accounting: Total Emissions (kg) Of 7 Air Pollutants Generated In Jersey 1998

POLLUTANTS:	Estimates based on:	
	Jersey-specific output- and expenditure-pollution coefficients¹	UK -adjusted output- and expenditure-pollution coefficients²
Carbon dioxide (CO2) as carbon	291,065,182	801,059,498
Methane (CH4)	961,262	5,830,095
Sulphur dioxide (SO2)	1,024,795	2,408,385
Nitrous oxides (NOx)	2,205,893	3,163,930
Non-methane volatile organic compounds (NMVOC)	2,403,511	1,916,683
Carbon monoxide (CO)	13,277,245	8,660,800
Nitrogen dioxide (N2O)	1,933	296,542

Notes:

- 1. Jersey-specific coefficients estimated using Jersey-specific fuel-use data and emissions factors**
- 2. UK-adjusted coefficients constructed by adapting UK-specific output- and final demand expenditure coefficients to reflect the composition of sectoral and aggregate outputs in the Jersey economy**

The second problem is the fact that the relative pollution intensities of sectors differ across the two sets of coefficients in Tables 6.15 and 6B.4. I illustrate this for the individual pollutant NO_x in Figure 6.1. In accounting terms the main impact of differing relative pollution intensities is on the estimated contribution of individual production and final demand sectors to total emissions in the base-year. I report the sectoral contributions (in percentage terms) to total emissions of the seven individual pollutants that are common to both sets of pollution coefficients in Table 6.18, and illustrate the results for NO_x in Figure 6.2. The direct contribution of each production sector, i , and final demand sector, z , to total emissions of any one pollutant, k , is determined by the emissions intensity of the activity in question and by the scale of activity. The scale of activity in each production sector, X_i , and final demand sector, C_z , is common to both calculations. Therefore the differences between the two sets of results shown in Table 6.18 and Figure 6.2 are entirely due to the differences in relative pollution intensities (including the zero intensity for all pollutants in the tourist final demand sector).

For example note from Table 6B.4 and Figure 6.1 that, according to the UK-adjusted coefficients, 'Land Transport' is the third most NO_x -intensive production sector in the Jersey economy. However, under the Jersey-specific measures it is only the sixth most NO_x -intensive, with an output- NO_x coefficient that is much smaller in relative terms. In the Jersey-specific set (Table 6.15) the 'Land Transport' direct NO_x -intensity coefficient is only 2.3% of the size of the coefficient for the most NO_x -intensive sector, 'Electricity', while this figure is almost 53% in the UK-adjusted case. In terms of contribution to total NO_x emissions, Figure 6.2 and Table 6.18 show that 'Land Transport' is attributed with the fourth highest contribution of all the production sectors under the UK-adjusted measure, accounting for 4.48% of total emissions. However, under the Jersey-specific measure this share is smaller both in absolute and relative terms: with a 0.36% share of total NO_x emissions, it has only the eleventh highest contribution of all the production sectors.

Figure 6.1 Direct NOx Intensity Of Production/Final Consumption in Jersey (1998) - Comparison Of Jersey-Specific And UK-Adjusted Direct Emissions Coefficients

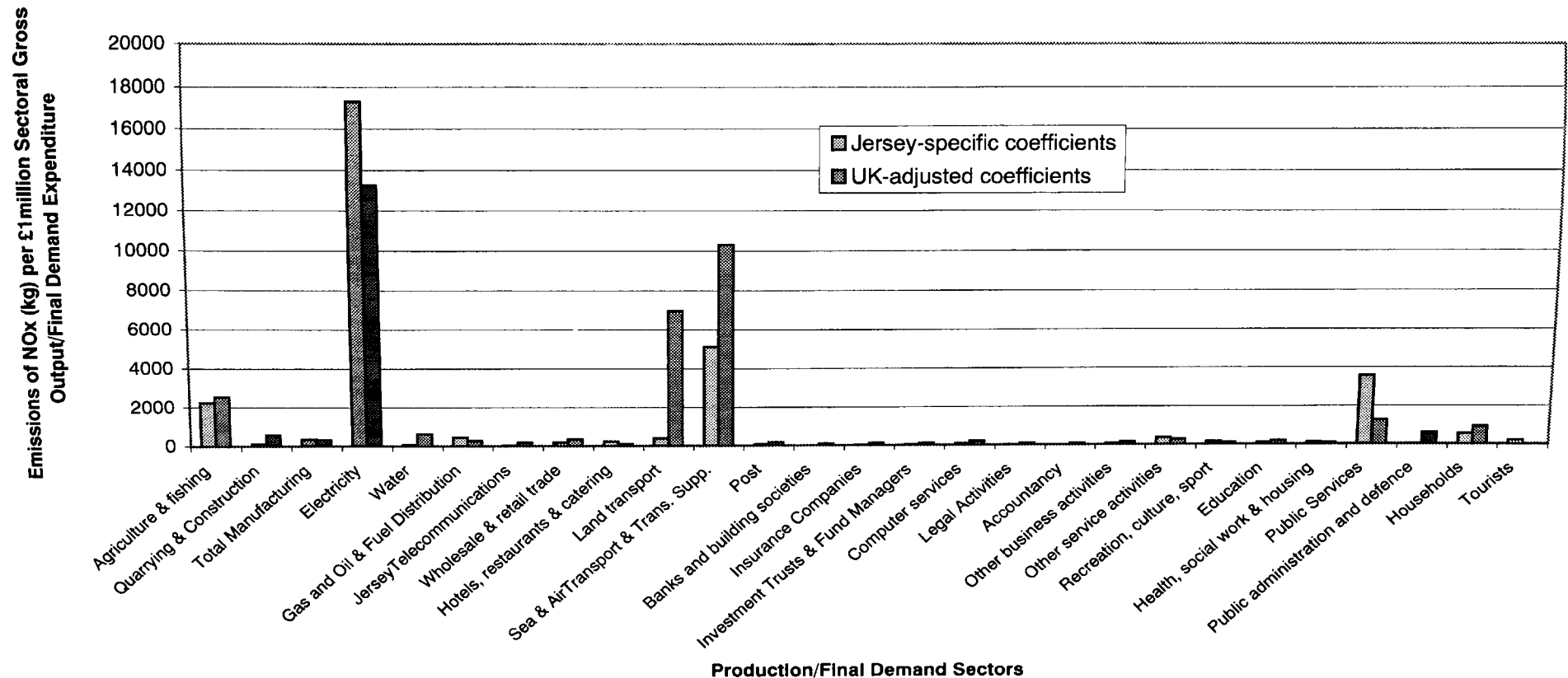


Table 6.18 Direct Contribution Of Production And Final Demand Sectors To Total Emissions Generation In Jersey (1998) - Estimates Using Jersey-Specific And UK-Adjusted Coefficients

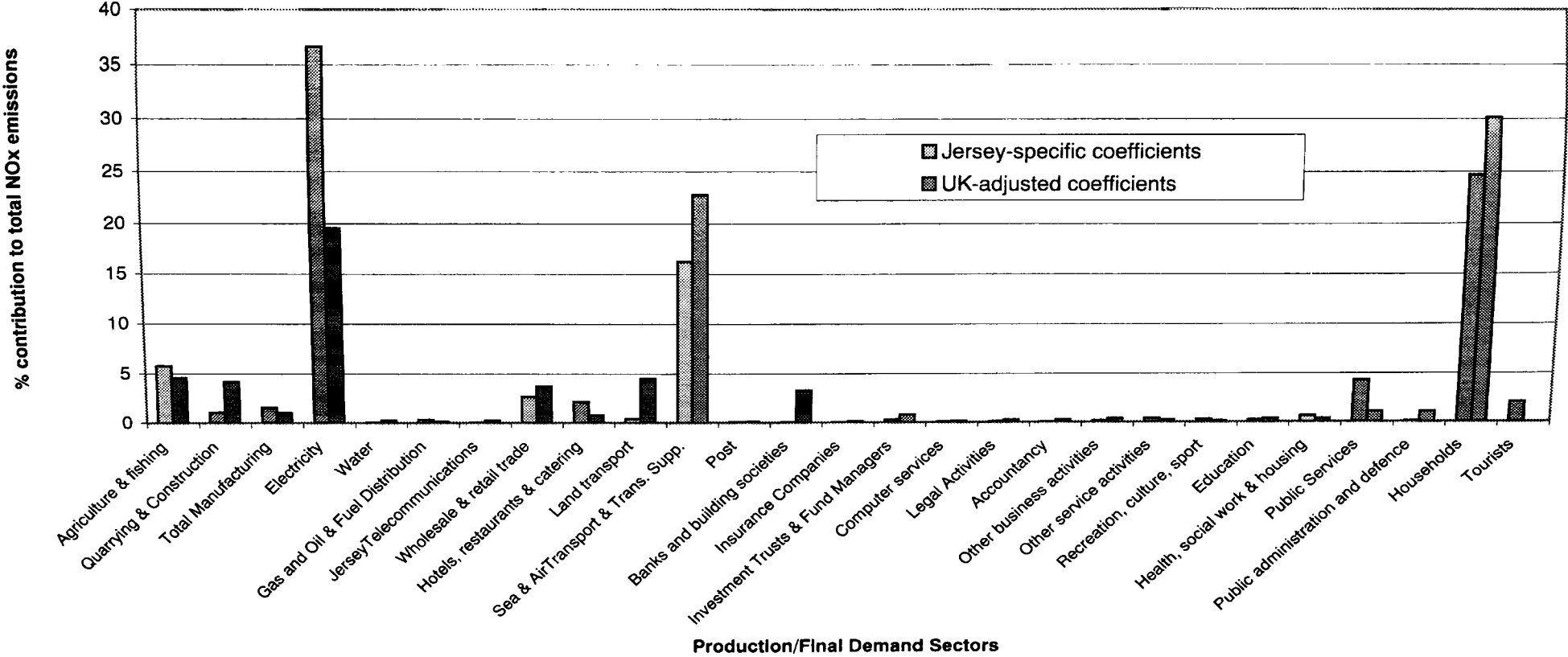
Estimates Using Jersey-Specific Direct Emissions Coefficients

Sectors	Agriculture	Quarrying &				Gas, Oil &	Jewelry	Wholesale &	Hotels, Rest.	Land	Sea & Air Trans.	Jewelry	Bank &	Insurance	Inv. Trusts &	Computer	Legal		Other Bus.	Other Service	Recreation,		Health, Social	Public	Public Admin.			
Pollutants	& Fishing	Construction	Manufacturing	Electricity	Water	Fuel Dist.	Telecom.	Retail Trade	& Catering	Transport	& Trans. Supp.	Post	Building Soc.	Companies	Fund Mgmt	Services	Activities	Accountancy	Activities	Activities	Culture & Sport	Education	Work & Housing	Services	& Defence	Households	Tourists	TOTAL
Carbon dioxide (CO2) as carbon	5.11	2.42	2.00	21.02	0.06	0.31	0.08	2.96	3.36	0.44	6.69	0.09	0.03	0.03	0.38	0.09	0.10	0.02	0.33	0.65	0.55	0.43	1.29	5.19	0.12	43.12	3.13	100
Methane (CH4)	82.73	0.03	0.03	0.02	0.00	0.01	0.00	0.17	0.06	0.03	0.15	0.00	0.00	0.00	0.04	0.01	0.01	0.00	0.02	0.03	0.01	0.00	0.00	0.35	0.00	14.90	1.41	100
Sulphur dioxide (SO2)	30.02	0.31	6.49	43.28	0.00	0.00	0.00	0.43	2.94	0.03	1.78	0.04	0.03	0.00	0.09	0.00	0.00	0.00	0.00	1.79	0.29	0.27	0.55	0.08	0.01	11.55	0.00	100
Nitrous oxides (NOx)	5.77	1.07	1.54	36.64	0.04	0.30	0.03	2.66	2.16	0.36	16.21	0.04	0.02	0.02	0.26	0.06	0.05	0.01	0.18	0.39	0.28	0.22	0.60	4.30	0.05	24.70	2.06	100
Non-methane volatile organic compounds (NMVOC)	0.63	0.43	0.51	0.46	0.05	0.21	0.04	2.47	0.71	0.37	4.17	0.01	0.00	0.05	0.56	0.14	0.09	0.04	0.28	0.44	0.10	0.02	0.06	11.50	0.01	70.02	6.81	100
Carbon monoxide (CO)	0.50	0.22	0.50	0.33	0.05	0.20	0.03	2.63	0.72	0.39	2.22	0.00	0.01	0.06	0.67	0.17	0.10	0.04	0.29	0.47	0.10	0.01	0.02	8.37	0.00	74.77	7.12	100
Nitrogen dioxide (NO2)	4.14	8.22	2.82	0.44	0.17	1.03	0.26	7.76	1.68	1.26	0.78	0.22	0.00	0.05	0.57	0.18	0.25	0.04	1.01	1.60	0.44	0.17	0.34	0.05	0.01	60.78	5.94	100

Estimates Using UK-Adjusted Direct Emissions Coefficients

Sectors	Agriculture	Quarrying &				Gas, Oil &	Jersey	Wholesale &	Hotels, Rest.	Land	Sea & Air Trans.	Jersey	Bank &	Insurance	Inv. Trusts &	Computer	Legal		Other Bus.	Other Service	Recreation,		Health, Social	Public	Public Admin.				
Pollutants	& Fishing	Construction	Manufacturing	Electricity	Water	Fuel Dist.	Telecom.	Retail Trade	& Catering	Transport	& Trans. Supp.	Post	Building Soc.	Companies	Fund Mgmt	Services	Activities	Accountancy	Activities	Activities	Culture & Sport	Education	Work & Housing	Services	& Defence	Households	Tourists		TOTAL
CO ₂ (carbon dioxide)	2.12	1.85	1.57	31.58	0.22	0.15	0.22	2.84	1.31	2.30	9.41	0.10	4.44	0.12	1.12	0.11	0.33	0.33	0.38	0.20	0.23	0.82	0.96	0.37	0.93	36.01	0.00		100
CH ₄ (methane)	44.43	0.04	0.01	0.54	0.00	2.47	0.00	0.04	0.02	0.02	0.17	0.00	0.06	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	50.46	0.01	1.66	0.00		100
SO ₂ (sulphur dioxide)	1.09	0.43	0.75	75.18	0.02	0.00	0.01	0.17	0.03	0.17	14.95	0.01	0.25	0.01	0.07	0.01	0.03	0.03	0.03	0.01	0.09	0.22	0.77	0.06	0.51	5.12	0.00		100
NO _x (nitrous oxides)	4.55	4.17	1.00	19.64	0.24	0.12	0.23	3.75	0.76	4.48	22.78	0.10	3.31	0.10	0.79	0.11	0.22	0.22	0.35	0.20	0.11	0.32	0.33	1.06	1.06	30.14	0.00		100
NMVOG (non-methane volatile organic compounds)	2.37	7.90	8.05	0.68	0.46	1.79	0.18	2.71	0.71	1.62	6.28	0.08	3.67	0.11	0.85	0.20	0.23	0.23	0.37	1.01	0.08	0.21	0.26	1.84	0.10	58.00	0.00		100
CO (carbon monoxide)	2.38	7.48	0.20	1.61	0.36	0.16	0.26	3.51	1.19	1.25	3.26	0.11	6.39	0.19	1.48	0.23	0.40	0.39	0.82	0.27	0.13	0.36	0.17	0.22	0.12	67.27	0.00		100
N ₂ O (nitrogen dioxide)	64.79	1.25	0.08	3.71	0.06	0.01	0.03	0.39	0.11	0.23	1.11	0.01	0.56	0.02	0.13	0.02	0.04	0.03	0.06	0.03	0.02	0.04	0.03	0.69	0.06	6.50	0.00		100

Figure 6.2 Direct Contribution Of Production And Final Demand Sectors To Total NOx Emissions In Jersey (1998) - Comparison Of Estimates Using Jersey-Specific And UK-Adjusted Direct Emissions Coefficients



Conversely, Figure 6.1 reveals that 'Hotels, Restaurants & Catering' has a higher NO_x-intensity both in absolute and relative terms under the Jersey-specific measure, being the ninth most NO_x-intensive production sector, compared with eighteenth in the UK-adjusted set. Figure 6.2 shows that if I were to rely on the UK-adjusted set of coefficients, 'Hotels, Restaurants & Catering' would be attributed with only 0.76% of direct NO_x generation, the twelfth highest contribution of all twenty-five production sectors. However, using the Jersey-specific measures, I find that this sector is attributed with 2.16% of total emissions, the sixth highest contribution. I would argue that these differences in the estimated relative pollution intensities and the contribution of different sectors to total emissions of each pollutant are as important as the variation in the estimates of total pollution generation reported in Table 6.17. This is because any errors in the relative pollution intensities or contribution of different sectors may distort policy priorities (e.g. if environmental policy is targeted at the sectoral level).

5.3 Factors Underlying The Variation In The Region-Specific And Adjusted National Estimates Of Economic-environmental Relationships In Jersey

5.3.1 Accuracy Of Data Collection At The National And Regional Level

I identify two main factors that may contribute to the differences in direct emissions intensities shown for equivalent sectors in the Jersey-specific and UK-adjusted sets of coefficients in Tables 6.15 and 6B.4:

1. Accuracy of data collection in Jersey and the UK levels.
2. Differences in fuel use (types and intensity) and polluting technology in Jersey and the UK.

I have already raised and discussed the first issue above. Due to the size of the Jersey economy, its island status, the structure of the energy supply industry and the availability of Coley's (1994) very comprehensive study on local pollution generation, I have been able to construct a highly detailed and accurate database on fuel use and polluting technology. In the case of an economy the size of the UK, it is unlikely that it would be possible to construct such a database. Even if a high level of resources were available for environmental accounting, it is unlikely that such detailed records of fuel supply and use would or could be kept for the UK. One important factor would be that patterns of fuel use are much more complex in the UK than in Jersey, where limited technology and competition among fuel and heating system suppliers constrains the choices available to producers and consumers.

Moreover, I would argue that my reporting of the construction of the environmental accounts for Jersey (1998) is characterised by a much greater degree of transparency than the UK NAMEA accounts. For example, as I point out in Section 5.1, the UK reporting does not include any information on what is assumed about polluting technology in order to generate sectoral emissions estimates. I explain that the UK acknowledges making adjustments that reflect problems in allocating fuel use and emissions from transport activities. However, these are unspecified. On the other hand, in the Jersey-specific case I clearly identify and state where accounting problems have arisen. This will allow rectification of these problems when and if improved data permit.

The second factor that will contribute to the differences in the UK-adjusted and Jersey-specific estimates is variations in fuel use (types of fuel and amounts used) and polluting technology in Jersey and the UK. Region-specific pollution coefficients ideally reflect the *actual* average emissions intensities (for each pollutant) of each production and final consumption activity that takes place in the regional economy. Adjusted national coefficients reflect the average emissions intensities for equivalent activities, *independent of the location of activity*. Therefore, as I explain in Section 5.1 above, adopting adjusted national coefficients to apply at the regional level generally involves

assuming that fuel use (type and intensity) and polluting technology at the regional level correspond to the averages observed for the national economy²⁸. However, if these assumptions are not valid, i.e. if one or more of the elements on the right-hand side of equations (6.3c) and (6.4c) differ significantly across national space, the adjusted national coefficients will likely mis-represent absolute and relative pollution intensities in the regional economy. This will in turn lead to errors in estimating total pollution generation in the economy and the contribution of individual activities to this total.

Even if the first factor, accuracy of data collection, is not a problem, if fuel use and technology are significantly different for equivalent activities in the UK and Jersey this will be sufficient to render use of pollution coefficients based on average UK technical relationships inappropriate.

5.3.2 Differences In Fuel Use And Polluting Technology In Jersey And The UK

The main motivation for investing resources in constructing a set of Jersey-specific base-year environmental accounts and pollution coefficients as part of this study is that important differences are known to exist in the technology used in certain activities in Jersey relative to the UK.

For example, all electricity produced in Jersey is generated using oil-powered technology while in the UK a combination of gas-, hydro-, nuclear- and oil-powered techniques is used to generate the total electricity requirement. Waste disposal is another example: in the UK there are emissions from landfill, while in Jersey all waste is disposed of by incineration or composting. Thirdly, the composition of technologies used for commercial and domestic heating activities in Jersey is different to that found in the UK. With no infrastructure for natural gas to be piped to Jersey it is necessary to import and bottle a combination of propane or butane. As a result, gas-heating systems

²⁸ As I explain at the end of Section 5.1, if fuller data are available at the national level – for example, on polluting technology (represented by the emissions factors, e_{ijt}^k , e_{zjt}^k , n_i^k and n_z^k) it would be possible to

are expensive relative to other forms of heating and a larger proportion of households and businesses therefore rely on oil-powered heating systems than is the case in the UK.

As I explain above, information is not available on the precise mix of polluting technologies used in the UK; in particular the UK trial NAMEA tables do not include emissions factors for comparison with the ones identified for Jersey in Section 3. However, the UK trial NAMEA table does include fuel use by sector that allows a direct comparison of the physical fuel use intensities of equivalent activities in the UK and Jersey. At the end of Section 5.1 above I derive a set of UK-adjusted fuel use coefficients (matrices $E_i^{UK(\theta)}$ and $E_z^{UK(\theta)}$), which can be compared to the Jersey-specific set (matrices E_i and E_z). If fuel-use in equivalent sectors differs significantly between Jersey and the UK, this alone will be sufficient to cast serious doubt on the validity of using the UK-adjusted pollution coefficients to estimate and model pollution generation in the Jersey economy.

First, consider the individual heating fuel, gas oil²⁹. Given the lack of infrastructure for piping natural gas to Jersey and the consequent reliance on oil-powered heating systems, I would expect to find higher heating oil use intensities in Jersey than in the UK. Figure 6.3 (below) reveals that this is indeed the case across most production sectors for gas oil use. Note that Figure 6.3 also reflects another peculiarity of fuel consumption and supply patterns in Jersey: while oil-powered heating systems are generally more prevalent in Jersey than any other type of heating system, gas oil is only used in the commercial sector. Domestic heating systems in Jersey run exclusively on kerosene (and the private household sector is the sole user of kerosene as a heating fuel). Therefore, while the aggregate UK household sector shows a positive, but relatively low, use of gas oil, the Jersey household sector has zero intensity for this fuel. This distinction between different types of fuel (e.g. kerosene or gas oil) used for the same purpose (e.g. running

derive adjusted national coefficients that rely on a weaker set of assumptions.

²⁹ Gas oil is technically the same fuel as the diesel used for automotive purposes; however it is standard practice to define and record supply of gas oil used for automotive purposes separately as 'diesel' (or 'derv').

oil-powered domestic heating systems) is crucially important because the pollution properties of different *types* of fuel can vary significantly. In the current example, the combustion of one kilogram of kerosene using the type of technology identified for heating systems in Jersey generates significantly smaller amounts of SO₂, NO_x and carbon monoxide than would result from the combustion of one kilogram of gas oil (see Table 6.5).

Therefore, if I were to assume that gas oil intensities are the same across equivalent sectors in the UK and Jersey, the result would be significant errors in estimating the amount of gas oil used at both the aggregate and sectoral levels. In terms of total fuel use in the economy, actual total gas oil use in Jersey for 1998 is almost twice as high as would be estimated using the 1998 UK-adjusted gas oil intensities. This is consistent with the explanation given above regarding the greater reliance in Jersey on oil-powered heating systems. However, more important in the present context is fuel use at the sectoral level. The fuel-intensities in Figure 6.3 demonstrate that assuming identical gas oil use for equivalent sectors in Jersey and the UK would lead to drastically misleading results, both in terms of the amount of gas oil used and the amount of emissions generated from this type of fuel use. This would be the case even if the technology used to combust this type of fuel were identical in the UK and Jersey, a factor that I do not have any knowledge of.

Given the very detailed information provided by energy suppliers in Jersey on stationary fuel-use (see Section 3.2.2) and the associated combustion technology that is available on the Island, I would expect fuel intensities in this area to differ from those found in the UK. However, I also find that automotive fuel use intensities differ across equivalent sectors in Jersey and the UK, even though there are not the same restrictions on combustion technology - i.e. there is no restriction on the type of vehicles that can be used on the Island. The combined petrol/derv intensities of the 25 production sectors, and aggregate households and tourists to Jersey are shown in Figure 6.4 (below).

Figure 6.3 Direct Gas Oil Intensity of Production/Final Consumption in Jersey (1998) - Comparison Of Jersey-Specific And UK-Adjusted Fuel Use Coefficients

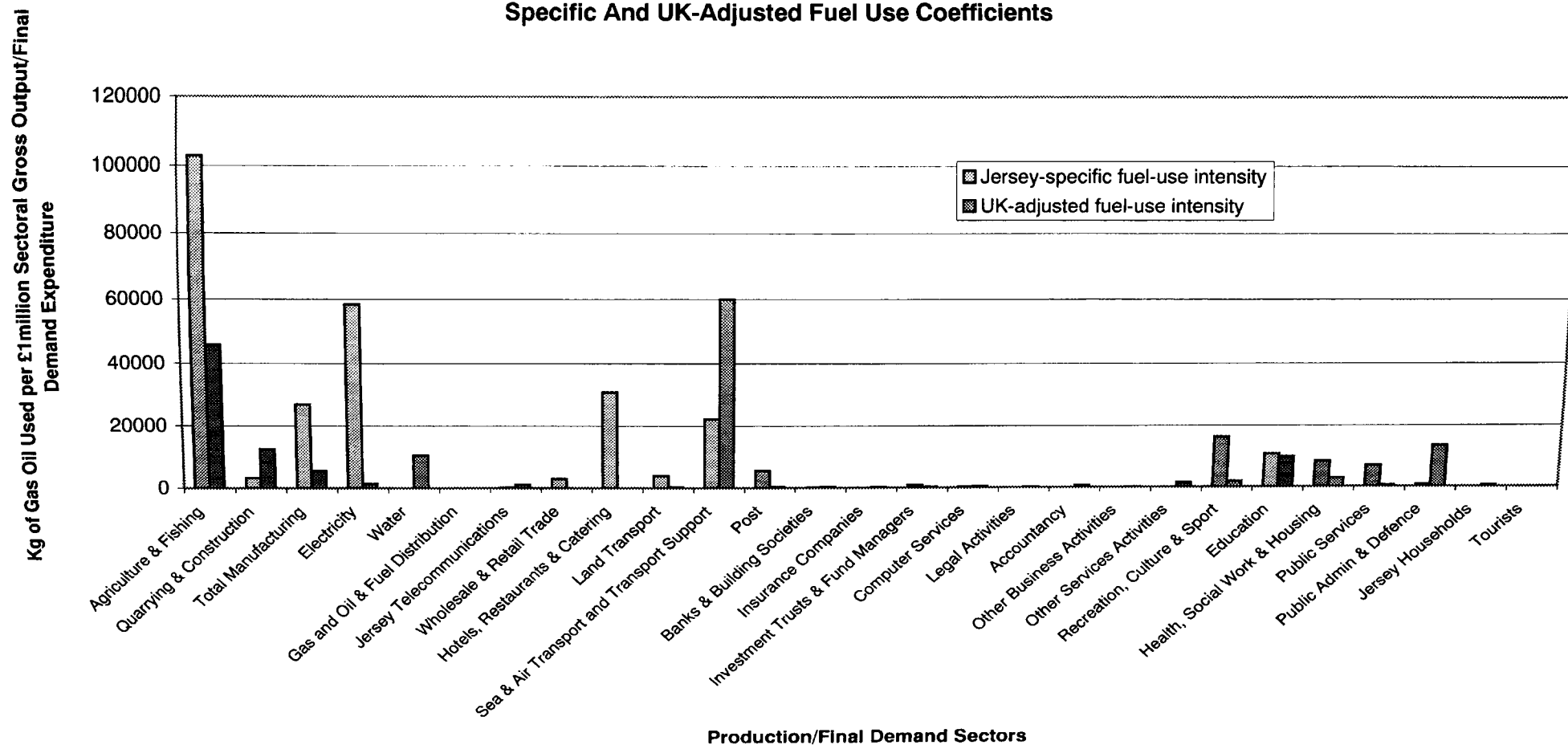


Figure 6.4 Direct Petrol/Derv Intensity Of Production/Final Consumption In Jersey (1998) - Comparison Of Jersey-Specific And UK-Adjusted Fuel Use Coefficients

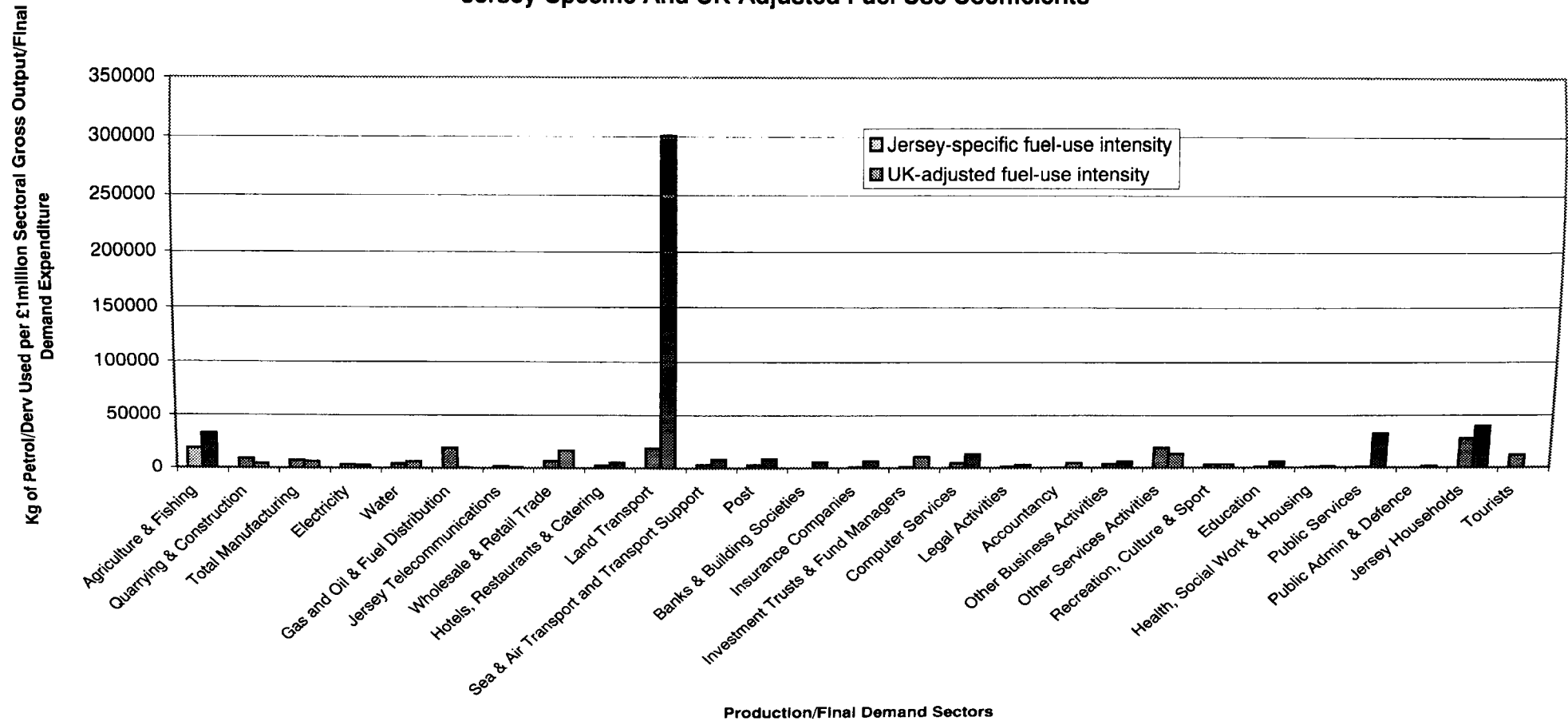


Figure 6.4 reveals that twenty out of the twenty-five production sectors are significantly less automotive fuel intensive than equivalent sectors in the UK would be. In particular, 'Land Transport' is far less fuel intensive than its UK counterpart, the value of its petrol/derv-output intensity being only 6.2% of the value of the UK-adjusted intensity. The other five production sectors - 'Quarrying and Construction', 'Total Manufacturing', 'Electricity', 'Gas and Oil & Fuel Distribution' and 'Telecommunications' - are significantly more automotive fuel intensive than equivalent sectors operating in the UK would be.

In terms of final demand sectors, note again that the UK figures do not separately identify fuel use by tourists, with the implication that I cannot determine the extent of any variation in automotive fuel use by visitors to Jersey compared to destinations in the UK. However total final consumption by Jersey households is significantly less automotive fuel intensive, despite the high level of private car ownership on the Island (of course this may be expected given the limited road space available to drive on).

So, just as I find in the case of stationary fuel use, it is clearly the case that automotive fuel-use patterns in Jersey are quite distinct from those that underlie the combustion-related element of the UK-adjusted pollution coefficients. Some of the differences in emissions intensities can be related to differences in the types of fuel use associated with their generation. For example, my results in Section 3 above indicate that the main source of SO₂ combustion related emissions from production activities that take place in the Jersey economy is stationary fuel use. Automotive fuel use, other than aircraft movements, does not generate SO₂ emissions. I have explained that the main type of fuel involved in stationary combustion in the production sector of the Jersey economy is gas oil. Examination of the output-pollution coefficients for SO₂ in Table 6.15 and Table 6B.4 and the gas oil intensities in Figure 6.3 show that it is the case that the Jersey-specific coefficients do tend to be higher (lower) than the UK-adjusted ones where gas oil intensities are higher (lower).

However, in general, the observed differences in the Jersey-specific and UK-adjusted pollution coefficients, and in the estimates of total emissions in Table 6.17, cannot be explained simply by looking at the differences in fuel intensities. As I explain above, no information is available about the emissions factors used to estimate the sectoral pollution levels reported in the UK trial NAMEA accounts. Without this and/or the type of breakdown of emissions by source shown here for the Jersey-specific estimates³⁰, it is difficult to determine whether violation of one or both of the assumptions required for adoption of the UK-adjusted coefficients alone can explain all the observed variation in results. It may be the case that the other potential explanatory factor suggested above, accuracy of data collection, is also important. Nonetheless, the crucial point is that, independent of all other possible explanatory factors, the observed differences in fuel intensities across the board in Jersey (1998) from what would be expected in their UK counterparts are *sufficient* to render use of pollution coefficients based on UK technical relationships inappropriate.

5.4 Wider Implications Of The Results Regarding Differences In Fuel Intensities In Jersey And The UK

The findings I report in this section have a significance that applies more generally than simply to the appropriate choice of pollution coefficients for economic-environmental accounting and modelling. Here I have examined the consequences of adopting national rather than region-specific energy-use and pollution coefficients to construct the environmental component of a regional IO system, the economic component of which has been generated using region-specific data. However, in Section 5.1 I note that it is sometimes the case that national data are used to generate the basic IO tables describing the structure of the regional economy. This is generally due to the resource costs involved in constructing regional economic accounts in the form of IO tables using primary region-specific data.

³⁰ This refers to the breakdown of emissions by polluting sector and source reported in Tables 6.3, 6.4, 6.6 and 6.7 in Section 3, and detailed for each pollutant in Appendix 6A (Tables 6A.1-6A.8).

There have been a number of developments in terms of how national coefficients can be adjusted to reflect the difference in level and composition of activity in the regional economy. Isserman (1980), Round (1983) and Richardson (1985) provide surveys of the basic methodologies adopted for this purpose. The most common approach appears to be some variant on the use of location quotients (LQs)³¹, which basically reflect differences in such factors as the level of employment, the export base, import requirements and/or specialisation at the regional and national levels.

However a critical observation is made by Round (1983). He notes that in some early developments of the methodology for deriving regional tables from national data there was confusion in relation to the distinction between differences in *trade* and differences in *technology*. While concluding that this confusion seemed to have been resolved, Round (1983) goes on to observe that developments tended to have been "geared towards the estimation of trade coefficients rather than technical coefficients" (p.193). It seems that this has continued to be the main focus of research. See, for example, reviews and discussion by Harrigan *et al* (1980b), Flegg *et al* (1995) and McCann & Dewhurst (1998).

There is no disputing the importance of differences in import requirements at the national and regional levels, or the resource costs involved in constructing region-specific technical coefficients. However, I would argue that my findings for Jersey imply that potential differences in technology may be of crucial importance. The fuel-use data for the UK and Jersey that were used to construct the region-specific and UK-adjusted fuel intensity coefficients for Jersey tell us the absolute physical amount of fuel used in each activity, regardless of whether these fuels are imported or purchased locally. The crucial finding of this part of my study is that differences in the energy (fuel) requirements of equivalent sectors at the national (UK) and regional (Jersey)

³¹ A location quotient (LQ) is a measure of relative concentration – e.g. a simple LQ would be the ratio between the regional and national proportion of employment or output attributable to a particular sector.

levels mean that the assumption of identical technical coefficients for this input-output relationship would result in extremely inaccurate and misleading results.

While it would be incorrect to generalise this result as applying to all input-output relationships and all national/regional economies, it would seem indicative that if such extreme results are observed in one case, investigation of potential differences in technology merits as much priority as factors like differences in trade. The types of region-specific data collection processes that have been carried out for Jersey *are* a costly investment. However, I would argue that these have apparently been cost-effective.

Focussing on the specific case of accounting for economic-environmental interaction, the findings in this section imply that very inaccurate results would be produced if I were to rely on using adjusted UK coefficients to estimate pollution generation in the Jersey economy. Of course, in relating my findings to the debate that is currently going on within the UK regarding the appropriateness of region-specific data collection and modelling, it is important to remember that Jersey is a very small economy, and one that is quite idiosyncratic in a number of ways. Therefore, I would expect to find greater variation from UK average fuel use and emissions intensities than would be the case in the Scottish, Welsh or larger English regional economies.

It may be argued that UK average emissions and fuel-use intensities might be more acceptable in these cases. However, for example, it is known that electricity is generated in Scotland using hydro and nuclear power methods that are less prevalent at the UK level. Moreover, many households in the North of Scotland do not have access to mains gas supply, which suggest that, as in the case of Jersey, there is likely to be a heavier reliance on solid fuels and heating oils than would be reflected in UK averages. Thus, at the very least, region-specific data collection to account for energy-use and pollution generation would be appropriate in the case of sectors where activity is known to differ significantly from national averages. However, I would argue that ideally a more

comprehensive and systematic approach to environmental accounting at the regional level is preferable. For example Harrigan *et al*'s (1980a, 1980b) study using Scottish and UK survey-based IO tables show that significant differences in technology exist throughout the Scottish and UK economies. Therefore, I would conclude that adopting an approach of attempting to adjust only for specific key polluting activities would be somewhat *ad hoc*, with the danger that important differences in fuel use and technology in a wider range of activities may be missed.

6 Chapter Summary And Conclusions

In this chapter I focus on completing the database required for the construction of a CGE modelling framework that is capable of capturing economic-environmental interactions in the target economy of Jersey. This involves generating a set of environmental accounts that are consistent with the economic accounts generated in Chapter 5. The 1998 Jersey environmental accounts constructed here form the base-year dataset of the environmental component of the CGE model of the Jersey economy. In Section 4 of this chapter I use the economic-environmental accounts to construct a set of matrices of Jersey-specific direct energy-use and emissions coefficients that fix the relationship between economic activity and physical energy consumption and pollution generation. However, I emphasise that the database constructed in this chapter is an extremely flexible one: while I explain that resource constraints preclude the development of input-pollution modelling in the current project, I have identified the coefficients required for doing so.

I would argue that one of the most significant elements of value-added from my dissertation is developed in this chapter. While the generation of the Jersey-specific IO table and SAM for 1998 (in Chapter 5) is an important development, this is not specific

to my thesis³². However, the generation of a set of Jersey-specific environmental accounts and pollution coefficients is a direct result of my own study. The results presented in Section 5 and Appendix 6B of this chapter demonstrate the added precision gained from making this development.

The environmental IO system that I construct in this chapter is potentially useful in its own right, aside from providing the environmental component of the CGE model. While the restrictive assumptions involved mean that using IO techniques to *model* the impact of changes in activity would be an inappropriate development, particularly for a supply-constrained economy like Jersey, the environmental IO system can be used for valuable descriptive analysis of the nature of pollution problems in Jersey. This is the focus of Chapter 7, where I use the Jersey environmental IO system for attribution analysis of the demand forces that drive pollution generation in Jersey. Then, in Chapters 8 and 9, I proceed to the stage of specifying a CGE model that can be used to track and explain the impacts of policy and other disturbances on environmental indicator variables.

³² In Chapter 5, Section 2, I explain that, while I have been given primary responsibility for construction of the Jersey SAM for 1998, both this and the development of the standard (economic) IO accounts are part of a wider project being carried out at the Fraser of Allander Institute.