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An analysis of UK climate change policy institutions and instruments

by

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Declaration of authors rights

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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ABSTRACT

Domestic action on climate change requires a combination of solutions, in terms of institutions and policy instruments.

I critically assess the Committee on Climate Change (CCC), an independent body which was created in 2008. I look at the motivation for its creation and in particular its ability to overcome a time-inconsistency problem by comparing it to another independent body, the Monetary Policy Committee of the Bank of England.

In practice the CCC appears to be the ‘inverse’ of the Monetary Policy Committee, in that it advises on what the policy goal should be rather than being held responsible for achieving it. The CCC incorporates an advisory function to achieve a credible carbon policy over a long time frame, similar to Stern (2006) but operating on a continuing basis and also incorporating a unique monitoring function. I conclude that the CCC could be more effective if delegated a policy instrument with which to achieve the UK carbon budgets.

The remainder of the thesis explores the idea of implementing such a policy instrument, in particular a carbon tax, in the UK by using multisectoral energy-environment-economy modelling techniques. However, a number of modifications to the input-output database are undertaken first in order to make the model more applicable to the policy analysis.

Firstly, the sectors included in EU Emissions Trading Scheme are identified and mapped to the economic sectors in the input-output table. Once the EU ETS identification complete I undertake an environmental input-output multiplier analysis of the “traded” and “non-traded” sectors. One significant result is that the electricity sector is important for the UK both in terms of output and emissions levels.

Therefore, secondly, I disaggregate the electricity sector in order to allow for substitution between electricity generation technologies of varying carbon-intensities. Again the multiplier analysis is undertaken but now with heterogeneous results for the electricity sector.

I then use the modified database to create a Computable General Equilibrium model which is used to simulate the effects of a carbon tax on the UK economy. Given that the carbon tax raises revenue for government it is appropriate to compare different methods of revenue recycling and in particular whether a 'double dividend' of improved environmental and economic conditions in the UK is possible.

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Chapter 1

Introduction and background

1. BACKGROUND ON CLIMATE CHANGE

According to the scientific consensus increasing levels of anthropogenic greenhouse gas (GHG) emissions, mostly from burning fossil fuels and land use, are rapidly warming the climate and raising global and regional temperatures.[1] This climate change is initiated by the greenhouse effect whereby excessive concentrations of certain gases in the atmosphere reduce the amount of infrared energy that can be omitted from the earth therefore unbalancing the energy absorbed and emitted by the earth's surface and this contributes to warming of the planet.[2] This warming may lead to a number of effects such as heating of the oceans, melting glaciers and ice caps, and changes to flora, fauna and species habitats. The potential risks and impacts involved in climate change are on an unprecedented scale and have potentially irreversible consequences for the planet. This warming may dramatically alter ecological conditions and typically adversely affect the human environment and *likely* result in increased droughts, rising sea levels and extreme weather conditions (IPCC, 2007a), accompanied by all the human and economic repercussions that these changes entail such as hunger, water shortages and flooding (Stern, 2006). This will occur unless there are vigorous policy responses for mitigation and adaptation. Unfortunately these responses and solutions are not simple because there are certain characteristics of climate change that render it a uniquely challenging problem. The current consensus is to limit the world temperature increase to 2 degrees Celsius from pre-industrial levels, any greater a temperature rise and we run the risk of more unforeseeable changes.

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[1] Greenhouses gases are water vapour, carbon dioxide, methane, ozone, nitrous oxide and halocarbons. Global concentrations of carbon dioxide have increased from a pre-industrial level of around 280ppm (parts per million) to 379ppm in 2005.

[2] For an overview of the science of climate change see The Royal Society (2010) and IPCC (2007a) and for a more detailed analysis see IPCC (2007b).

Although knowledge and understanding have evolved dramatically over the last decades, there is still a large degree of uncertainty associated with many aspects of the science and economics of climate change which make it difficult to address. The complex and intricate nature of the underlying mechanisms means that little regarding these predicted changes can be said with precision, especially given the long time frame involved. This uncertainty underpins many of the difficulties faced by climate change policy, and makes finding an agreed solution extremely difficult. [3] One major scientific problem has been in understanding how GHG concentrations directly affect the temperature because the climate system is inherently complex and unpredictable in nature. Only recently has it proved possible to attach probabilities to temperature rises associated with different GHG concentrations (Stern, 2009). This has allowed some quantification of risks but the science is still far from definite and precise results are heavily dependent upon model specification.

GHG emissions are a worldwide negative externality, of a scale that is unprecedented. It is particularly difficult to deal with a public bad produced by all nations (with some nations producing a lot more than others[4]) because no worldwide authority exists with the power to regulate emissions. The uncertainty involved also means we cannot realistically agree on how to undertake a cost-benefit analysis which would receive worldwide consensus on the exact implications of potential temperature rises.

Agreeing on how to measure and value the costs and benefits of mitigating climate change is extremely difficult and involves many moral decisions. For instance, discounting plays a major role in any economic analysis of climate change because, with positive time preference, future outcomes should be discounted more heavily than the same outcome today. However, agreeing on an appropriate discount rate has been one of the most contentious aspects of the economic analysis of climate change and the choice of discount rate will seriously affect the outcome of any analysis in

[3] See McKibbin and Wilcoxen (2002) and Ingham and Ulph (2005) on uncertainty in climate change
[4] See MacKay (2009) for a detailed breakdown

terms of the balance of costs and benefits.[5] Discounting is also linked to the intergenerational element of climate change analysis because many of the people living today will not be among those most directly affected by expected climate change. It will be future generations who are impacted most severely if no action is taken. The actions of citizens today will affect the rights, opportunities and freedoms of future generations and so the assumptions made on how we value costs and benefits to future generations within our discount rate will heavily impact upon any analysis. However, it is also the case that those future generations will likely be wealthier than the current one and can therefore better afford the costs of mitigation and adaptation. Therefore it is inescapable that ethical and moral discussion must form part of the analysis on discounting and intergenerational aspects.[6]

"In short, uncertainty is the single most important attribute of climate change as a policy problem. From climatology to economics, the uncertainties in climate change are pervasive, large in magnitude and very difficult to resolve."(McKibbin and Wilcoxen, 2002, p115)

In practice, given the worldwide scale of the issue, we have thus far relied upon voluntary international agreements to coordinate action to tackle climate change. International agreements, however, are accompanied by a whole host of coordination and distributional issues, especially under uncertainty.[7] Getting a coalition of countries to agree on how to allocate emissions reductions among themselves is a near impossible political task. There are large free-rider incentives that exist which limit the amount of action likely to be taken by individual countries.[8] The global bad of climate change requires worldwide emission reductions in order to stabilise temperature, but each country has an incentive to let the others do the work to reduce emissions and free-ride without any effort. Therefore we have something similar to a

[5] For instance see Stern (2006) for a methodology and responses and criticisms to Stern from Weitzman (2007) and Nordhaus (2007). It is possible that a discount rate could also take a zero value or even be negative.
[6] For a recent discussion of these see Stern (2009) chapter 5. Also see Dietz (2008) for an overview of various other approaches to the economics of climate change.
[7] There is extensive literature on coordination and distribution with regards to the Kyoto Protocol as well as other IEAs. Among other see Bohringer, (2003) and Barrett and Stavins (2003)
[8] Finus (2006) show that free-rider incentives can be overcome to form stable coalitions if benefits from abatement are sufficiently high or with an appropriate transfer scheme.

prisoner's dilemma where no country is willing to make significant reductions given that the others will likely benefit by not reducing their emissions and so we have a Nash equilibrium where no country takes action. However, the problem can be seen as a repeated game where collusion over time is a possible stable solution.

Achieving that collusion through an international agreement, given the number of countries involved and their heterogeneity has proved incredibly difficult to achieve in practice. On top of that, each country has different GDP per head, growth rates, physical endowments and historical emissions paths which bring in equity and fairness considerations to negotiations. Reaching an agreement on emission reduction targets is especially difficult given that developing countries are likely to be the first and most adversely affected by climate change yet are the least responsible for the increased emissions levels over the last century[9]. Achieving any political consensus on climate change has therefore proven to be a substantial challenge.

1.1.International action

There has been one international agreement that imposes reduction targets on GHG emissions for developed nations, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). It was agreed upon in 1997, ratified in 2005 and runs from 2008-2012. It requires individual nations to limit their emissions relative to 1990 levels with the aim of stabilising the climate in 2100. Although Kyoto has been seen as a necessary initial step, it has achieved only moderate success so far and suffers from a lack of participation and ambition (Barrett and Stavins, 2003). Kyoto allows for the use of flexible market mechanisms in tackling emissions reductions; International Emissions Trading, Joint Implementation and the Clean Development Mechanism.[10] In theory these should allow abatement to take place in the most cost effective manner i.e. where it is cheapest, and also allow for the diffusion of low carbon technologies to developing

[9] See MacKay (2009) appendix 1
[10] Articles 17, 6 and 12 respectively

countries. This ‘market mechanism’ approach has been taken further through the introduction of a European Union Emissions Trading Scheme (EU ETS) in 2005 in order for the EU collectively to reach their commitment under Kyoto.[11] However, the EU ETS only covers around 50% of GHG emissions therefore significant domestic reductions will be required to meet the remainder.

The Copenhagen Accord was signed at the Conference of Parties in December 2009 in an attempt to provide a successor for the Kyoto Protocol, but this is not a UN agreement. Copenhagen has certainly placed more emphasis on the requirement of national commitments and schemes for tackling domestic reductions. The difficulty in achieving a stable consensus and agreement was shown here as national interests became the main obstacle to agreeing a treaty to which all parties approved. Copenhagen is seen as a failure by many for moving away from the UNFCCC Kyoto framework to a non-binding one.

However, the Copenhagen Accord has provided a basis for agreement on long-term stabilisation levels and for setting national emissions reduction targets – though not with any specific overall framework and cap, as exists under Kyoto. The Copenhagen approach may well proceed more rapidly than the Kyoto-type process as it does not require acceptance from all UN countries for decisions to be passed. It is an opportunity for the major emitters to begin taking steps towards reduction. For the first time the USA and China, the two biggest GHG emitters, have signed up to an agreement on climate change, a step that was not achieved through Kyoto and is seen necessary if global emissions are to be reduced to the required level to stabilise temperatures. To some though this shows a lack of intent and is meaningless if the agreement is not binding.

Also Copenhagen has outlined commitment for transferring climate funds from developed to developing nations. These funds will assist both mitigation and adaptation. Some warming is inevitable. Consequent to increased emissions over the last century, we have already seen the world mean temperature rise by 0.8^{o}C.

[11] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003

Therefore there must also be decisions taken on an appropriate adaptation plan by each country. These will vary greatly as countries' experiences of warming will differ by various factors such as geographical location and income levels.

Although market mechanisms such as taxes and trading schemes are vital in achieving the necessary emissions reductions cost-effectively, Kyoto stresses that they have limitations which mean that it is still absolutely essential that each country takes responsibility for ensuring their own emission reductions through other measures such as technology R&D support and information provision. It is also necessary that domestic emissions reductions take place to ensure developed economies become low-carbon in the long run, because developing countries alone cannot achieve the necessary abatement in the long term and also because developed countries are mostly responsible for historic emissions.[12] The Kyoto Protocol stresses the importance of domestic reductions and not completely relying on market mechanisms created by the protocol i.e. that there must be a balance between wider market mechanisms and domestic action because all countries will require to be low carbon in the future once cheaper abatement options have been exhausted. [13] This commitment to domestic reductions should provide the incentive for domestic investment in technologies required to achieve a low carbon future. For the reasons discussed above there is now a shifting consensus that domestic emissions reductions must play a large role in efforts to tackle global climate change. Domestic action can come in the form of pure regulation e.g. efficiency standards, and also additional market mechanisms such as a carbon tax or national emissions trading.

[12] Historical emissions have been a topic of major debate in international negotiations with developing nations laying the blame of climate change with developed countries. This is a moral question as to how the cost of global reductions should be spread.

[13] Article 6(1) (d) and Article 17 of the Kyoto Protocol created Joint Implementation and Emissions Trading respectively and both stress that the flexible mechanisms are 'supplemental to domestic actions' in achieving the emissions reduction goals of the protocol. They do not specify the balance between these. The Clean Development mechanism created by Article 12 is in a similar vein in that any reductions must be 'additional' to reductions that would have otherwise happened anyway.

1.2 Domestic action

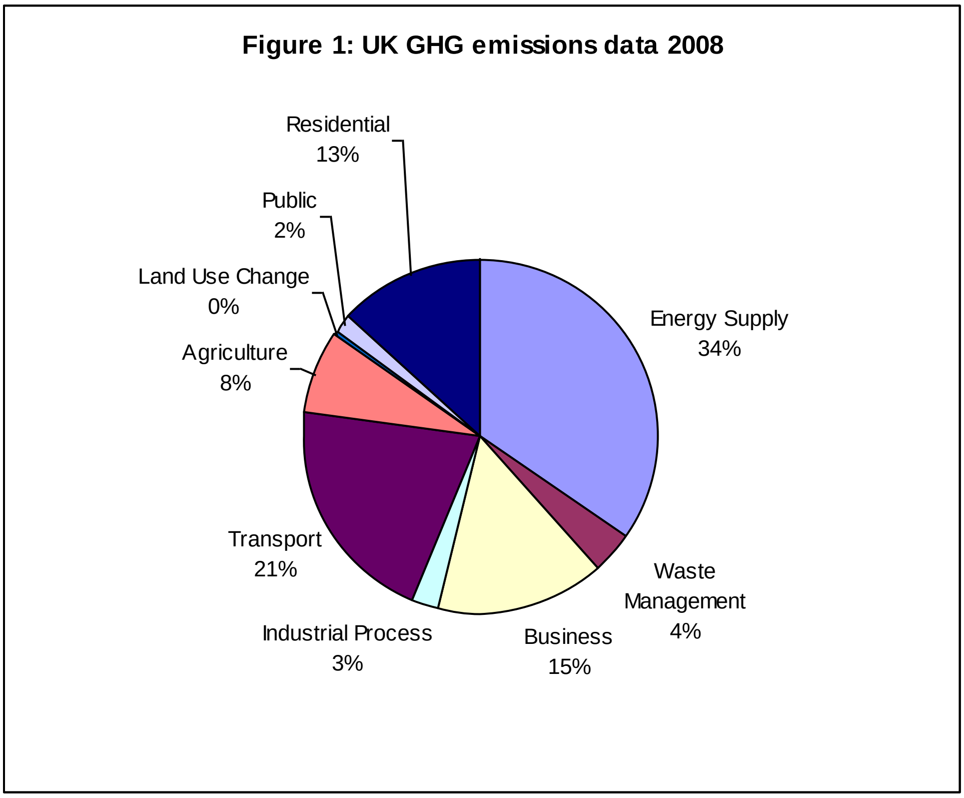
The UK government is introducing regulation and policies to encourage and enable movement towards a low-carbon economy. In doing this it hopes to show leadership on climate change, given the UK's historical role as an emitter, which will then inspire other countries to commit to reductions as well. "This leadership argument is best understood in game theory terms: it is an attempt to induce steps towards a global carbon cartel to reduce the quantity of emissions."[14] There is also an argument to introduce the necessary changes sooner rather than later, given that change will be costlier in the future if we are already locked-in to a high carbon economy. Although the scale of these costs is dependent upon how future costs are discounted.

Total UK GHG emissions are mostly generated by energy, transport and business but there are also substantial emissions from the agriculture and residential sectors (Figure 1.1).[15] Carbon dioxide is the largest GHG emitted, accounting for 85% of UK GHG emissions in 2008, while the other main gases are methane and nitrous oxide (quantified in carbon dioxide equivalent). Around 50% of UK GHG emissions are already covered by the EU ETS, mostly from the energy sector but also the mineral and paper industries.

The current UK energy institutional arrangements are already rather complicated. Helm (2007a) suggests that the UK has a new energy paradigm. He notes that the energy institutional setup is geared towards the market settings of the 1980s and 90s but that new policy emphasis on climate change and security of supply is not represented within this. The institutional arrangements require radical reform to meet these new challenges.

[14] Helm (2007c)
[15] Transport by households is included within the residential sector and not the transport sector.

Figure 1.1: UK GHG emissions for 2008 per economic sector



Source: DECC (2010a)

There are energy related institutions, such as the regulator Ofgem, which have been present for some time and the government has recently created new institutions, such as the Carbon Trust and Energy Saving Trust, and instruments, such as the Climate Change Levy (CCL), Feed-in tariffs (FiTS), the carbon reduction commitment (CRC) and Renewable Obligation certificates (ROCs). It seems so far that these institutions and instruments have been *ad hoc* at best, creating a complex structure for industry and investors.

However, climate change must be viewed as one goal within energy policy as a whole and, indeed, government policy more generally. There are other government energy policy goals, such as security of supply and affordable energy prices, which are interdependent (and potentially conflicting) both with each other and all other environmental goals.[16] More generally there is a possible conflict between pursuing the objectives of continuing economic and population growth, while simultaneously seeking to reduce emissions.

Table 1.1: UK main Energy and climate change institutions overview

Institution	Purpose	Type	Start date	Funded by
Ofgem	Regulates the gas and electricity markets	Non-Departmental Public Body	2000 (merger of two existing bodies)	The various energy suppliers that Ofgem regulates
Energy Saving Trust	Provides free, impartial advice and information for those interested in saving energy	Independent organisation	1993	DECC, DEFRA, DfT, devloved governments and private sector e.g. EDF Energy
Carbon Trust	Helps companies and organisations to lower carbon emissions and funds low carbon technologies	Company	2001	DECC and partly by the Climate Change Levy
Sustainable Development Commission	Provides independent advice to government on sustainable development	NDPB	2000	Various government departments
Nuclear Decommissioning Agency	Clean up UK's nuclear legacy in a safe and effective manner	NDPB	2004	DECC, HM Treasury and devolved governments
Committee on Climate Change	To advise and monitor government progress towards emissions reduction targets	NDPB and statutory body	2008	DECC

[16] The Scottish Government also has a further goal of using energy as a source of economic growth by promoting renewable energy sources

In addition to what was an already complicated institutional setup the government has initiated a major new organizational change with the creation of a climate-change-specific body, the Committee on Climate Change (CCC). This is an independent body, established by the Climate Change Act (2008). It is tasked with advising on the emission reduction targets through carbon budgets that the UK Government should set in order to play its part in mitigating climate change. Following the CCC's advice the Climate Change Act has committed the UK to achieve a GHG emissions reduction of 80% by 2050 from 1990 levels. As an interim measure to this long-term goal in 2050, GHG emissions are to be reduced by 34% by 2020.

The CCC is the first environmental body of its kind. There are a number of policy instruments available to policy-makers to achieve the carbon reductions required under the Climate Change Act. In this thesis I aim to discuss and explore a number of issues related to current UK climate change policy in terms of both policy institutions and instruments. Firstly, I wish to analyse the CCC by exploring why it was created, evaluating its remit and asking what part it can play in UK policy. In the remainder of the thesis I turn my attention to policy instruments needed to achieve emissions reductions. I construct and use a model capable of simulating one such market mechanism, a carbon tax, and ask what the system-wide impacts are for the UK economy of meeting its carbon targets through introducing a carbon tax that raises revenue.

There appears to be growing acceptance that such bottom-up domestic climate change policy is the way forward in terms of international cooperation on tackling climate change rather than the existing top-down centralised framework such as Kyoto (Guardian, 2012; Stavins, 2012). Other nations have taken similar measures to tackle climate change at a national level. GLOBE International (2013) is a survey of national climate change legislation in 33 countries and their report states that 32 of the 33 countries have progressed with their legislation in 2012. In 2012 Mexico passed their General Law on Climate Change which requires them to achieve domestic reductions in emissions of 30% from business-as-usual in 2020. This is seen as particularly important as it is the first large developing country to legislate for such a commitment. Australia has introduced a Clean Energy Act with a carbon tax which will become an Emissions Trading Scheme in 2015 in order to achieve an 80&% reduction in emissions from 2000 levels by 2050. Through the Act they also created a Clean Energy Regulator which will administer the carbon pricing and a Climate Change Authority which will provide advice to the Government on setting reduction targets and reviewing the carbon price mechanism.

Other recent major developments have been South Africa including a carbon tax in their most recent budget; as has Japan; South Korea introduced legislation to create an emissions trading scheme by 2015; China is preparing its first national climate change law, and the State of California has recently held its first auctioning of emissions permits. The implementation of many of the recent legislation has been influenced through discussions with other experienced domestic climate change legislators including the UK. However, Canada has regressed in terms of climate legislation by repealing the Act which implemented the Kyoto Protocol.

The Danish Government created a Commission on Climate Change in 2008 which appears to work similar to the CCC in it provides advice to the Government on how Denmark should phase out fossil fuels in the long term and also it has a similar composition in that there are ten members of the Commission which have a scientific background on many aspects of climate change. However, this body is not enshrined in legislation the way the CCC is and Denmark does not have the same carbon budgets as the UK. Instead the Commission was tasked with offering potential policy instruments to achieve a reduction reliance on fossil fuels. In France the Grenelle I legislation on the environment setup a committee "Comité national du développement durable et du Grenelle de l'Environnement" which oversees the environmental laws put in place and once a year reports to Parliament to suggest improvements. Further research which compares and contrasts the various national climate change frameworks and in particular their institutions would be beneficial for understanding why there are differences in approaches between nations and where lessons can be learned.

2. THESIS STRUCTURE

In Chapter 2 I analyse the role and remit of the Committee on Climate Change (CCC). The CCC was introduced in 2008 as an independent body that would be critical in achieving a transition in the UK to a low-carbon economy. Therefore it is appropriate to analyse the purpose, structure, and role of such a body and consider specifically what it adds to the policy mix. I discuss all the possible reasons for its creation and although there may be several, I argue that the most compelling is in order to solve a time-inconsistency problem which occurs in carbon policy. It is seemingly inspired by the model of the Monetary Policy Committee (MPC) of the Bank of England and so I directly compare the two bodies highlighting the differences and giving potential reasons as to why these differences occur. It appears that the CCC is in fact the inverse of the MPC in that it advises on the policy goal while the MPC achieves the policy goal. A significant conclusion of the analysis is that the CCC could be more effective it was given control of a policy instrument, most likely a carbon tax, in order to achieve the carbon budgets.

I then evaluate the CCC and the different tasks it is required to perform. The CCC is charged with many extra considerations, while operating in a field with many other energy related institutions. There are potential tensions between the CCC carbon budgets and other policies on different spatial scales, be they national, regional or international. It must be noted that there are large areas of overlap between international environmental agreements and domestic action, and the extent to which these policies and instruments reinforce or undermine each other merits detailed comment. In particular, the concept of having national emissions targets, efficiency improvement targets, and renewable policies simultaneously with the EU ETS seems, in theory at least, inefficient because multiple policies lead to higher costs. This is unless some extra benefits are brought from having additional policies such as improving efficiency by overcoming market failures or delivering other social objectives, such as security of supply, distributional goals or political feasibility (Sorrell and Sijm, 2003). In Appendix B I briefly extend the discussion in Chapter 2 and focus on a regional aspect of domestic climate change policy with respect to Scotland and in particular the Climate Change (Scotland) Act. I firstly compare the spatial differences of international, EU, and UK climate change policy and ask whether it is then appropriate for Scotland to pursue its own direction and whether it is even possible to do so.

Given that a significant conclusion to Chapter 2 was that the CCC could be more effective if delegated an instrument then the remainder of the PhD thesis focuses on policy instruments to achieve emissions reductions. In particular the remaining chapters concentrate on the construction of a multi-sectoral energy-economy-environment computable general equilibrium model in order to consider the effects of the introduction of a carbon tax on the UK economy to achieve the carbon budgets. The model is multi-sector in order to capture the effects from policy where emissions and energy-use often differ substantially across industries. So the composition, as well as the level, of activity is crucial for the level of emissions. A general equilibrium model is required because interactions and feedback between sectors will determine the effects of any environmental policy and such a model will also identify its aggregate impact on the economy. However, before simulating any scenarios, I address two important issues with regards to the database in order to make the model as flexible and relevant as possible to the real-life conditions and climate change policy considerations. The basis for the database is an input-output table of the UK for 2004.

In Chapter 3 I attempt to identify the economic sectors that are included in the "traded" sector of the EU Emissions Trading Scheme which is the largest climate change policy instrument currently in place in the UK. The EU ETS currently covers around half of the UK's total carbon dioxide emissions and therefore any model which wishes to analyse current policy must be able to distinguish the "traded" EU ETS sectors. An input-output (IO) table is constructed as the base year database and I describe how the EU ETS sectors are mapped to the database. However, there are several issues that make it difficult match the EU ETS coverage to economic sectors in the database and these issues are discussed. Once the sectors covered by the EU

ETS are identified and the IO database is constructed, the database is used to calibrate an IO model. The model distinguishes between the "traded" and "non-traded" sectors of the EU ETS so that every economic sector comes under one of those headings. I conduct an IO multiplier analysis to compare the effects on the economy in terms of output and emissions of changes in demand from the "traded" and "non-traded" sector. A major conclusion from the analysis is that the electricity sector is a substantial emitter of carbon dioxide and that reducing emissions in this sector is absolutely essential for the transition to a low-carbon economy.

Based on the importance of the electricity sector for achieving emission reductions, stressed in Chapter 3, in Chapter 4 I disaggregate the electricity sector within the IO database into various electricity generating technologies. These include both fossil-fuel generators such as coal and gas as well as various other low-carbon technologies such as nuclear, hydro, wind and marine. I describe in detail the methodology employed to achieve this disaggregation. Due to a lack of available data on sales and purchases by the electricity companies, it is not possible to have a bottom-up approach and must be disaggregated based on a top-down basis. I conduct a similar multiplier analysis as in Chapter 3 but now focussing on the significant differences in carbon-intensity between the various electricity generating technologies.

In Chapter 5 I simulate a revenue-neutral carbon tax on the UK economy of £22 in order to achieve the emissions reduction target imposed on the government of a 34% reduction in GHG emissions by 2020 from 1990 levels.[17] The use of the IO framework from Chapters 4 and 5 is limited as it imposes restrictive assumptions on technical relationships within production and also assumes a passive supply-side of the economy. Therefore I develop a single-region CGE model of the UK which overcomes many of the limitations. The chapter begins with a discussion of the theory of externalities and how price and quantity market mechanisms can be used to internalise such an externality. The strengths and weaknesses of a carbon tax are then laid out. The case for using such a tax as a policy instrument may be strengthened significantly if there is the potential for a double dividend. I then describe various

[17] This target translates into a 35% reduction in CO_2 emissions from 2004 in the model.

aspects of CGE modelling in general including the background and theory underpinning this type of modelling. I consider the model structure and form of a typical CGE model, its strengths and weaknesses, and why such models are often used as tools for analysing policy issues and in particular environmental policies. Given the magnitude of the CGE literature and types of model, I keep this to a very general discussion. After this I review several other national CGE models which have previously simulated a carbon tax and highlight their findings. These cover many different nations and I describe the several different methods of policy simulations and revenue recycling which they all implement.

The remainder of the chapter concentrates on modelling the carbon tax. I describe the structure of the UKENVI model used and how emissions and energy are modelled. This includes a description of the assumptions made regarding the labour market and elasticities determining the substitution between various parts of the production function and the economy, energy and environmental data necessary to create the model. The simulation approach of the carbon tax is described and the three scenarios are outlined with regard to the tax revenues. These scenarios are: 1) no revenue recycling, 2) additional revenues finance an increase in government expenditure, and 3) additional revenues finance a decrease in income tax. Then the economy-wide results and impacts of the carbon tax are presented and discussed. These results show the importance of how revenues from the carbon tax are recycled in order to limit the effects it has on reducing output and employment. A sensitivity analysis around these results is carried out to test how parameter vales (and labour market assumptions) affect outcomes.

In Chapter 6 I summarise the results of the research undertaken in this thesis. I highlight each of the major findings of each of the chapters. Taken broadly the major findings of the thesis is that the CCC is the inverse of the MPC in the sense that it can be thought of as a continuous version of the work on climate change by Stern (2006) but with an additional monitoring function. The CCC could be given more powers by delegating it a policy instrument most likely in the form of a carbon tax. The remainder of the thesis explores the possible use of a carbon tax to achieve the

UK carbon budgets and whether a double dividend of both reduced emissions and improved economic activity is possible. It concludes that of all the three recycling methods in the simulations that if revenues from the tax are recycled through reductions in income tax then emissions targets are achieved and also the economic costs of the carbon tax are minimal although no double dividend is possible in the long-run. There is also a discussion in Chapter 6 of how the research could be improved through more detailed data sources and possible future extensions to using this formulation of the UKENVI CGE framework with a disaggregated electricity sector.

Chapter 2[18]

An analysis of the role and remit of the Committee on Climate Change

1. INTRODUCTION AND BACKGROUND

The Climate Change Act (2008) created the Committee on Climate Change (CCC). The CCC is an independent body which is tasked with helping the UK achieve its emissions reductions targets and ensure the transition to a low-carbon economy. Given that it is the first body of its kind, it is necessary to analyse the underlying motivation as to why the independent body was created and what was is its exact purpose is in the UK climate change policy context?

Section 2 is a discussion of a range of possible motives for delegation of carbon policy to an independent body. In each case I discuss what institutional setup would be suitable and what other alternatives may be available. Section 3 of the paper describes the CCC's structure, functions and its tasks. Section 4 identifies what I believe, given the preceding analysis, to be the reasons for the creation of the CCC and its main roles. This involves a comparison of the CCC with the MPC and suggests that, in light of its current structure, the CCC is in practice better viewed as playing a 'Rolling Stern plus' role due to its advisory and monitoring functions, rather than being directly comparable to the MPC. Section 5 provides an evaluation of the CCC which includes a discussion of the setting of budgets, 'extra considerations', monitoring functions and how domestic carbon budgets interact with the institutions and instruments on various spatial levels e.g. EU ETS and renewables targets. Section 6 then concludes.

[18] Research from this chapter has been accepted and published in *Energy Policy*, Volume 41, pp. 466-473 in February 2012

2. REASONS FOR DELEGATION TO AN INDEPENDENT BODY

In order to achieve their policy goals, governments have a number of possible options. Examples are command and control regulation, market mechanisms or institutional changes. One such option is to create a separate body, independent from government, which is given specific roles or powers – essentially removing the issue from the political process. Such an independent body can take many possible forms, depending on its purpose.

In this section I begin by identifying a number of possible purposes for which an independent climate change body could be created. This entails a discussion on the appropriate composition of such a body and outlines the policy levers that would seem appropriate to give the body in each case. The potential purposes considered are: information provision; advisory role; monitoring function, and policy delegation. Of course an independent body could, in practice, combine a number of these roles.

2.1 Information provision

Accurate and timely information on climate change is necessary for informed policy response, investment and decision making. Information and evidence on updated science and emissions data at a national, industry or company level are all needed for accurate analysis and to inform both public and private sector decision-making. The government may wish to enhance the credibility of the climate change information by delegating the responsibility for gathering and distributing such data to an independent agency. This is a possible consideration because statistics coming directly from government may be manipulated for political purposes. A recent example of such delegation is the Office of National Statistics (ONS), which became independent from government in 2007 in order to enhance the credibility of the data that it publishes. Since this independence there have been issues over communication of data and, on occasions, undue pressure has been placed upon ONS staff from government departments. In December 2008, the Home Office released statistics on knife crime early, against the advice of the ONS who suggested that the data could easily be incorrectly interpreted. This political interference was heavily commented upon by the media and senior government officials, and resulted in a public apology by the Home Office (BBC News, 2008b). Clearly, *ceteris paribus*, the independence of the statistical body increases the credibility of information provided, given that when under direct government control, manipulation could, and has, occurred.

A similar motivation as with the ONS could be behind a delegation in climate change as the same argument on information credibility could easily be applied to the provision of climate change or energy related information. This information may be in the form of scientific evidence, statistics or advice from independent experts.

An independent body adds credibility because the information comes from an autonomous source rather than direct from government. The government could quite easily undertake this role and provide the information itself but the public may be sceptical of the resultant data because they anticipate a degree of political manipulation with regards to the accuracy, comprehensiveness and/or timing of information being released (see 2.4.1 on Political Pandering below for a fuller discussion). This could lead many pressure groups, such as energy suppliers/users and environmental campaigners, to question the validity of official data and issue rival statistics in order to challenge government figures. This in turn may lead to the saturation of public information on climate change and cause considerable confusion. Voters become unsure who to believe and this can be frustrating, leading to considerable apathy on the issue. Therefore an independent body may appease stakeholders and be agreeable to all concerned as a main supplier of reliable information. The public may also be more likely to accept the sometimes negative consequences of combating climate change and to take action to curtail their carbon footprint because they believe in the validity of the statistics and the credibility of the agency. MacKay (2009) stresses the importance of using clear figures and advice to the public concerning what they can actually do to lower their carbon use in the most efficient and meaningful way. If demand for energy use is to be substantially reduced through lifestyle and consumption changes over time, this may be best achieved through a central climate change information body.

A climate change information body of this type should have a similar structure and setup as the ONS. This would consist mainly of a staff of scientists, statisticians and economists who can collate climate change information centrally and disseminate it in a simple manner for government and public consumption. Some of this work is currently done by the Carbon Trust, an independent body which works to improve energy efficiency in the public sector and businesses and to promote investment in renewable energy technology.

2.2 Advisory Body

Another possible reason for the creation of an independent climate change body would be to provide unbiased scientific advice to the UK government on climate change issues. Advisory bodies of this nature are common-place in government in the form of Quangos or non-departmental public bodies (NDPB), as they are now called. As of March 2008 there were officially 410 UK advisory NDPBs, 41 within DEFRA. Examples include the Sustainable Development Commission and the Royal Commission on Environmental Pollution (as well as the CCC).[19] Similar bodies also have a role in the private sector, often going under such names as: advisory board, committee, council or authority, where organisations feel they benefit from input from experts out-with their own organisation who can give a fresh or experienced perspective. A further example is The Scottish Council for Development and Industry.

The government would have to make a decision on the exact remit of such a climate change advisory body in order to determine what precisely it is supposed to advise on, as such a body might have a range of possible functions. This remit could be as explicit as necessary. It may relate to one specific aspect e.g. advise precisely on how to lower emissions from transport. On the other hand, it may be more general, focussing on the science of climate change or it may also incorporate social or

[19] See Cabinet Office (2008) for a full list.

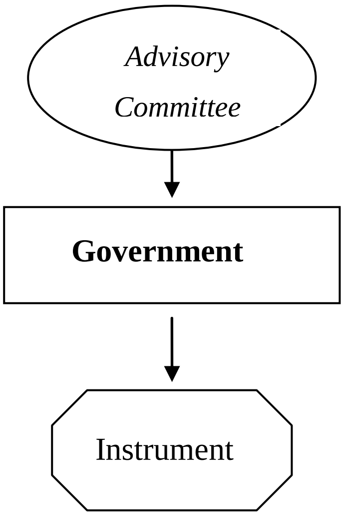
economic aspects. However, especially given the range of issues involved in climate change, it is advisable not to have too limited a remit, as this may be to the detriment of another important area. This is then a question of getting a balance between the remit of the body and existing bodies in terms of overlap of purpose. It is crucial not to miss out on important policy areas but also it would be inefficient for significant overlap between institutions.

In general how successful a body will be is significantly determined by its members' expertise, and the greater this is, the more detailed its advice can be and this should maximise the quality of the relevant information set available to government for decision making. This expertise however must be backed up by sufficient technical support to produce detailed analysis. This is especially important in climate change due to its complex interdisciplinary nature. Therefore appointing the appropriate individuals in the first place is critical in gaining the largest benefits from the creation of an advisory body on climate change. A climate change advisory body would therefore not have any members representing the ordinary public but be comprised entirely of experts in the field of climate change, from various backgrounds.

A climate change advisory body could inform government, providing it with expert advice on the level of emissions reductions needed to move the UK to a low carbon economy. This advice could also go further to include a breakdown of where exactly emissions occur, where they could be most easily reduced and advice on the specifics of available policy options. A softer advisory body could be seen purely as a source of data and statistics (see Section 2.1 above) for government to make informed decisions about policies on climate change, similar to the independent Office of National Statistics, but combined with advising the government on specific technical issues. A tougher advisory body would advise on a wide-range of areas in great detail and probably combine its advisory capacity with other roles.

The advice given could be used to set and/or implement emission reduction targets. The government can choose to implement these actions itself or delegate the responsibility of achieving targets to another separate body by giving it control of a policy instrument or lever.

Figure 2.1: Functioning of advisory body in policy structure



Stern (2006) emphasises the important international aspects of tackling climate change. So such an advisory body would preferably provide advice at international, national and regional levels. It could inform domestic policy on climate change and also the UK's role in international climate change agreements.

2.3 Monitoring

An independent body could also play a purely monitoring role. In this case, the government or another body would set the goals e.g. emissions reduction target, the government (or separate body) would attempt to achieve these goals. Afterwards the monitoring body would judge whether these objectives had been achieved, whether through a quantitative or qualitative analysis or both. Given the nature of the problem this would likely involve monitoring whether reduction targets are being specifically met. This work would entail assessing whether goals were being achieved in a timely manner and done to a sufficient level of precision. The findings would be public knowledge, available for further scrutiny and comment. This process would be repeated on a regular basis. Such a monitoring body would investigate the results the government believes it has achieved, and therefore its independence must be absolute (see 2.4.1. below for a discussion on the requirement of delegated body members' independence). Access to information and a high level of transparency are necessary within the monitoring process to allow accurate and credible reporting. Access to information will require detailed data on both the public and private sector, and on projects aimed at cutting emissions. Transparency is critical in the success of any monitoring body. Only through such an open process can the electorate have confidence in the monitoring process. If there is any ambiguity with regards to the information then credibility may be lost.

An effective monitoring body would also have the power of sanctions in order to deter non-compliance by the government or the body tasked with achieving the previously set goals. It may be very difficult to achieve a credible sanction because financial or legal penalties cannot be easily imposed. However some sort of public embarrassment or "shaming" may be appropriate as a possible sanction. A further possible sanction option would be a legal challenge to individual decisions or non-compliance with legally binding emissions reduction targets. (These legal issues are discussed further in Section 5.1)

Whether the imposition of sanctions is automatic or not is also relevant here: if left to the monitoring body's discretion, this could result in inconsistent outcomes and varying degrees of severity i.e. the monitoring body has authority over whether, and to what degree, the government has met targets and also sets the level of any imposed penalty. A number of sanction options may be appropriate on a case-by-case basis, although consistent application of agreed criteria for determining the sanction would be critical. In monetary policy a sanction exists where a letter must be sent by the Governor of the Bank of England to the Chancellor of the Exchequer if inflation deviates too far from its intended rate, this is intended to work as a form of embarrassment but also as a means of publicly explaining why such a deviation has occurred and what response is planned. Although not severe, this rule does provide for consistent transparency in the monitoring process by requiring a public response to targets not being met. If this sanction were to occur regularly then perhaps the position of the Governor or the MPC members may be questioned.

A monitoring body would likely comprise officials who have the ability to check in-depth whether targets have been achieved by government. Most likely, a good knowledge of climate change science and policy would be essential in order to interpret details and make the monitoring process more credibly robust. These individuals would most likely be highly regarded figures of integrity, whose independence is beyond doubt in order to achieve the necessary credibility. The monitoring body could be anywhere between being simply a purely numerical independent review and verification of government figures, to commenting upon whether government targets are being met and requesting a response where they are not, or even imposing sanctions where available. As carbon policy incorporates many diverse sectors of the economy it is not possible to have a regulator in the same way as happens in financial markets or even gas and electricity markets, due to their disperse nature.

2.4 Policy Making

The government may delegate actual policy or decision making to an independent body for a variety of reasons, which are outlined below.

2.4.1 Political pandering

The government may delegate decision making powers to an independent climate change body in order to remove the ability of the government to manipulate policy for other political purposes. This motivation is similar to that for independent information provision but in this instance the devolved body has decision making powers rather than simply an information provision role. Even without any intertemporal aspect or comparison to the MPC (this is developed further below in Section 2.4.2) delegation may be efficient and provide benefits. Political pandering occurs where an incumbent government, faced with re-election, chooses policies that will appeal to the public in order to improve their chances of being elected again, in essence, pandering to voters regardless of whether voters' beliefs are correct or welfare enhancing. This assumes, realistically, that most voters have incomplete information and little incentive to investigate all policies in detail, so the role of government in this case should not necessarily be to follow voters' wishes but rather to act in the voters' best interests, on occasions when they have a more accurate information set. However, it also assumes that government is motivated almost wholly by re-election and this incentive can often be in direct contradiction to acting in the voters' best interest. Therefore there are occasions where allowing decision making by politically accountable officials may result in the setting of a suboptimal policy outcome purely for political gain. Removal of policy making in sensitive areas to independent experts can have beneficial welfare effects especially where the public are less well-informed. Maskin and Tirole (2004) suggest that "technical decisions, in particular, may be best allocated to judges or appointed bureaucrats"[20] but that discretion should be limited in such cases and Helm *et al* (2003, p439) says specifically in the context of carbon policy that delegation "reduces the possibility that governments, driven by the next election and other short-term political economy considerations, will set carbon policy inappropriately."

In order to bypass any political pandering an independent climate change committee would have powers to make decisions which public opinion may not always favour. In practice it is highly unlikely there will be the degree of political will required to allow delegation of full decision making. For instance serious carbon reductions may require substantial increases in fuel prices, but it is certain that a tough fuel price accelerator, for example, would not be popular with the public.[21] Therefore the government (principal) would not be willing to allow this degree of power to be delegated out-with its own control (to an agent). The catch twenty-two is that delegation is a good option for government where policy is likely to be unpopular because it means the public cannot blame them for any perceived negative

[20] Maskin and Tirole (2004)

[21] For an example see the effect of industrial action by heavy vehicle drivers on fuel prices in 2008 (BBC, 2008a)

consequences of the decision, but by delegating the government loses control of important decision making powers, the government may end up in a worse-off position than it would have been has it retained control and made the decision itself.

Delegation also has close links with regulatory capture theory (Stigler, 1971) where companies in heavily regulated industries e.g. energy, use their proximity to regulators to influence or manipulate the government in order to limit new entrants and retain market power. This is really a specific case of political pandering, where government is pressured into making politically beneficial decisions for a specific industry, rather than the whole electorate. In return the government may receive political backing in the future. Basically there are rents from regulation and policy which existing firms will try to capture. In order to bypass this possibility a government may delegate regulation to an independent body that has less possibility of being influenced by the private sector. Helm (2007a, p33) states as much with regards to regulatory capture and political pandering:

“The design of institutions which can provide policy credibility to private investors has been a major preoccupation in Britain in the regulation of privatised industries and in monetary policy. The main requirements are to minimise the scope for capture by regulatees and prevent intervention based on short-term political considerations. These aims are best achieved through an element of statutory independence with an associated emphasis on technical expertise. Independence gives the formal separation of functions, while expertise enables the regulatory body to build up reputation.”

It is necessary however to distinguish between political capture and general regulatory capture which could still occur i.e. some capture of independent bodies may still take place. Whether this happens depends on the incentives of the members of the delegated body. If they are truly independent and their incentives cannot be unduly influenced by industry then it is possible to escape from inefficient regulation. The composition of an independent body with policy making powers is therefore of the utmost importance to its success and this applies to all of the motivations for delegation that have been mentioned, not only avoiding political pandering. The purpose of a body will surely influence the composition of its members e.g. a conservative central banker regulating monetary policy when the requirement is monetary prudence. More generally, for any type of delegation, if it is a purely technical body then scientists should be appointed, likewise if business orientated then those with business knowledge and experience must play an important role. A balance has to be struck between types of members appointed to a body in order for there to be a fair, well-rounded outcome that has input from people with quality but varying expertise. This diversity will give the body more scope and range in its conclusions, which may be beneficial but depends upon its objective. In this specific case, it is likely that the composition would be diverse in terms of fields of study given the complex and interdisciplinary nature of climate change.

Capture theory may also be more applicable if an independent body, through constant contact, becomes increasingly aligned with industry. The high frequency of the interaction a body has with industry, and a greater understanding of the industry's problems, may well lead such a body gradually to become more sympathetic towards the industry.

There is obviously some alignment of incentives required for the CCC to act in accordance with government's wishes because the body is being given a direct task by government, but the extent to which such bodies are independent in this principal-agent relationship depends on their composition. Committee member's incentives must not be completely aligned with those who delegate in the first place, otherwise the delegation is worthless as no-one will believe that the body is genuinely independent. However, most importantly, members' interests must be congruent with government in terms of commitment to the climate change issue. Perhaps, in order to incentivise properly, performance related pay, i.e. bonuses for hitting targets set by government, could be implemented for members of a committee with delegated policy powers.

2.4.2 Time Inconsistency in climate change policy

In environmental policy there is a time inconsistency problem that arises when attempting to reduce emissions and this appears to have been a major consideration leading to the creation of an independent climate change body. Significant reductions in emissions require considerable irreversible private sector investment which in turn depends on knowledge of long-term government carbon policy and other energy policies. For example, if it is expected that carbon emissions will be taxed heavily in the long-term or that a permit trading system will be in place, then investment in renewables will increase as they become more cost competitive. The tax or permit system will raise the marginal costs of dirtier energy sources and make investment in cleaner sources more attractive to investors. However, if there are issues about certainty of the tax then a time inconsistency problem may occur as follows: Firstly, government sets the tax/permit level for emissions and then secondly, the private sector responds accordingly by increasing investment in renewables and energy efficiency measures. However thirdly, after the sunk investment from the private sector, the government may have an incentive to backtrack on their carbon policy *ex-post* for their own political benefits e.g. lowering carbon taxes or increasing tradable permits to stimulate output, enhance competitiveness, reduce energy prices or alleviate fuel poverty. Investor's expectations incorporate this and they therefore believe that the government will renege on its promises, and so under-invest in the necessary low-carbon technologies.[22] This is the time inconsistency problem and it occurs because governments face multiple goals in a short lived time frame i.e. their carbon policy is not credible.[23] In essence this is a quandary caused by the political process and also the multiple and often conflicting policy goals.

The time inconsistency problem arises from the fact that the policy maker has discretion, but if the policy maker can somehow commit to pre-determined tax rates

[22] That there is a time-inconsistency issue in the UK is an ex-ante theoretical assumption made during this thesis. However, it would benefit from further analysis as to whether time-inconsistency is the case in practice. This could be carried out through econometric estimation as to whether there has been a structural break in investment in renewables after the CCC came into existence in 2008. This may be difficult to decomposing the many factors which affect investment in renewables.

[23] The government face multiple goals at the same time but once industry has invested in a technology, the governments trade-off may change

(most likely increasing in robustness over time), perhaps through the use of a promise or contract, then the time inconsistency problem can be circumvented. Therefore it is necessary to give investors credible expectations on future policy in order to induce the required investment but how can this be achieved?

Marsiliani and Renström (2000) set out a two-period model where time inconsistency occurs because the government has an incentive to raise an energy tax in the second period to redistribute from low to high productivity workers. They propose that earmarking of taxes is a solution in this instance to time-inconsistent behaviour with regards to pollution. Abreggo and Perroni,(2002) have a similar model where time inconsistency arises due to redistributional concerns, although here there is an incentive to lower the tax in the second period, and suggest that this can be partially overcome by using subsidies to offset the emissions tax.

Helm *et al* (2003) summarises the time inconsistency problem in a non-technical manner and suggests that it could, at least partially, be solved through the delegation of carbon policy to an independent energy agency. They set out a model in which welfare is maximised when the government can credibly commit to a policy rather than under discretion. The rationale behind this energy agency is that a long-lived independent institution can influence the expectations of investors through reputation. Helm *et al* (2003) argues that if the independent agency can sustain a credible reputation, then it should be delegated the social welfare function to optimise. Theoretically this would involve the government outlining society's goals (e.g. setting weights on increasing output and reducing unemployment and emissions) and delegating responsibility for maximising the welfare function to the body which controls a number of policy instruments. In the absence of reputation the body may be delegated a single policy instrument, similar to the MPC, or a modified welfare function, akin to that of a conservative central banker. Helm *et al* (2003) also presents the option of an agency with no policy instrument, which only monitors government performance and provides recommendations meeting the targets where necessary. Such a body would "increase transparency and hence credibility, but not be wholly convincing"[24] and this is the outcome that Helm believed was the most likely for the UK.

D'Artigues *et al* (2007) also solve a similar time-inconsistency model but involving only two possible technology choices and the possibility of renewable subsidies through negative tax rates. Brunner *et al* (2010) discusses credibility in carbon policy and suggests that the three possible options for achieving credible carbon policy are legislation, delegation and securitization. In terms of delegation they distinguish between advisory and agency types of solutions.

A full model solving time inconsistency in carbon policy is outlined fully in Helm *et al* (2004).[25] A model of industry and government interaction in the production of energy is set out and solved for the cases of government discretion and commitment in exactly the same manner as below.

Firms

Energy demand, Q, has constant price elasticity:

(2.1) $$Q = \alpha P^{-\varepsilon}$$

Where P is an index of energy prices, $\varepsilon > 0$ is the price elasticity of demand and $\alpha > 0$ is a constant. In this model price equals average cost.

Emissions, E, are a linear function of energy output:

(2.2) $$E = eQ$$

$e \in (0, e_D)$ is a dirtiness parameter and the emissions per unit output of the dirtiest technology is e_D, whose cost of production is lowest at c_D. There is a set of possible production sets with the dirtiness parameter, e and production costs, c, inversely related to each other.

[24] Helm *et al* (2003) p446

[25] D'Artigues *et al* (2007) also solve a similar time-inconsistency model but involving only two possible technology choices and the possibility of renewable subsidies through negative tax rates.

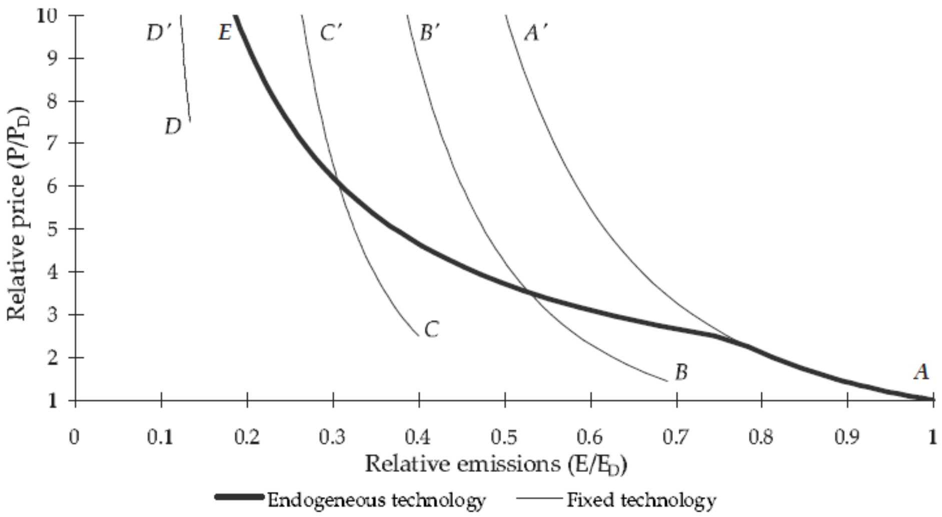
(2.3) $$e \geq \beta c^{-\sigma}$$

The above condition must hold, where σ is an elasticity parameter and $\beta = e_D c^{\sigma}_D$, so that the firm with dirtiest technology has the lowest emissions and cost combination. Total costs for industry are *c*Q.

Government has a carbon tax, *t*, as its policy instrument and thus with identical firms, total average costs are *c* + *te*.

Assuming there is Cournot competition with free entry, then entry will continue until price equals average cost. Given this market form, firms place themselves on the technology possibility set where expected costs are minimised, *c* + E[*t*]*e*, subject to $e \geq \beta c^{-\sigma}$. Where E[*t*] is the expected tax rate on emissions.

Figure 2.2: Relationship between relative prices and relative emissions



Source: Helm *et al* (2004)

Optimal cost and emissions choices for a given carbon tax are:

(2.4) $$c(E\{t\}) = \max\ [c_D, (\sigma\beta E\{t\})^{1/1+\sigma}]$$

(2.5) $$e(E\{t\}) = \min\ [e_D, \beta(\sigma\beta E\{t\})^{-\sigma/1+\sigma}]$$

For a particular technology choice of cost and dirtiness (ċ, ė), the relationship between prices and emissions can be parameterised by the tax rate, t. From first two equations:

(2.6) $$E(t) = \dot{e}\,d\,P(t)^{-\varepsilon}$$

Figure 2.2 illustrates the relationship between prices and quantities relative to a baseline of no carbon tax. The curves A to D represent fixed technologies (ċ, ė), where the curve *AA*' is reflects the most polluting technology and *BB*' to *DD*' are respectively cleaner technologies. Increasing the carbon tax will increase prices and reduce emissions moving north-west along such a curve. Point A reflects the instance of no carbon tax and the dirtiest technology.

When firms can choose technologies i.e. not fixed, and therefore respond endogenously to the tax rate, increasing *t* will inevitably lead to investment in clean technologies. So this relationship becomes:

(2.7) $$E(t) = e(t)\,d\,P(t)^{-\varepsilon}$$

Where *e*(*t*) is given by (*e*(E{t}) above - equation (2.5). Assuming expectations are fulfilled such that E[t] = t, substituting equation (2.5) into (2.7) gives the relationship between prices and emissions.

Welfare

The welfare function in the model consists of: change in consumer surplus s(P); tax revenues r = *t*E; and disutility from pollution *z*(E).

(2.8) $$\omega = s(P) + \nu r - \lambda z(E)$$

Where λ is the weight on pollution and ν is the marginal benefit of public funds from the emissions tax, both measured relative to consumer surplus. For an isoelastic demand curve, the change in consumer surplus relative to a given baseline price level P_D is given by:

(2.9) $$s(P) = \alpha/1\text{-}\varepsilon\ [P_D^{1-\varepsilon} - P^{1-\varepsilon}]$$

And with a simple specification of disutility of emissions (where $\gamma > 0$) as

(2.10) $$z(E) = E^{\gamma}$$

We can describe welfare as a function of tax by combining (2.9) and (2.10) to give:

(2.11) $$\omega(t) = \alpha/1\text{-}\varepsilon\ [P_D^{1-\varepsilon} - P^{1-\varepsilon}] + \nu t E(t) - \lambda E(t)^{\gamma}$$

<u>Solution under commitment</u>

When government can commit to a tax rate, there is dynamic game in which there is complete information. This moves sequentially: (1) The government announces and commits to a carbon tax rate *t*; and (2) the private sector forms expectations of the tax rate, with E[*t*] = *t* under commitment, and so makes technology choice (*c*, *e*). This is solved by backwards induction. For a given carbon tax, the private sector costs and emissions are simply c(t) and e(t) in equations (2.4) and (2.5). The policy maker knows the reaction curve and sets the carbon tax to maximise the welfare function in equation (2.8). The first order condition for the policymaker is therefore:

(2.12) $$\left.\frac{d\omega}{dt}\right| = \frac{\partial\omega}{\partial t} + \frac{\partial\omega}{\partial c}\frac{dc}{dt} + \frac{\partial\omega}{\partial e}\frac{de}{dt} = 0$$

From which there is an optimal tax rate t^*, from which the technology choices are given by substituting into equations (2.4) and (2.5). The optimal tax for government is the point on the firm reaction function that maximises the welfare function in Figure 2.3. There exists a unique interior commitment solution (t^*, c^*, e^*) as the welfare function is concave and the firm reaction function is convex which is the diamond in Figure 2.3. See Proof 1 of Appendix in Helm *et al* (2004) for this.

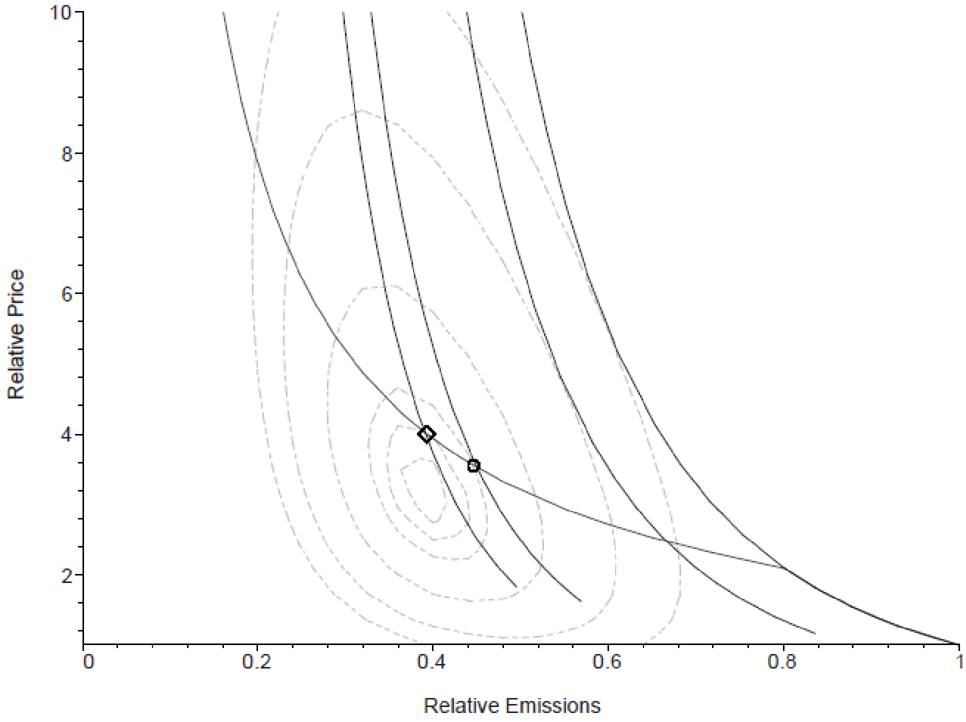
Solution under discretion

When government retains discretion to alter the tax rate *ex post*, another dynamic game of complete information is played in the following order, where this time the private sector moves first: (1) the private sector forms their expectation of the tax rate E[t] and thus chooses their optimal (c, e); then (2) the government chooses the tax rate t given the firms' technology choice. Solving by backwards induction, the government reaction function, t(c), is given by the solution to the first order condition:

(2.13)
$$\left.\frac{d\omega}{dt}\right| = 0$$

i.e. The policymaker chooses the carbon tax which maximises its welfare function for a fixed technology choice such as the curve AA'. There exists a unique interior discretion solution (t', c', e') in which there is a lower relative price but greater relative emissions than the commitment solution. This is the circle in Figure 2.3.

Figure 2.3: Discretion and commitment solutions for *v* = 0.8



Source: Helm *et al* (2004)

<u>Conclusion of model</u>

These solutions of discretion and commitment produce different outcomes on most occasions because "the marginal effect of the tax is different before and after technology choice".[26] The elasticity of damage to emissions is lower after investment; however tax revenues are more responsive to the tax rate after investment. Therefore the time inconsistency problem depends upon which is most prevalent – the changed elasticity of emissions or tax revenues after investment.

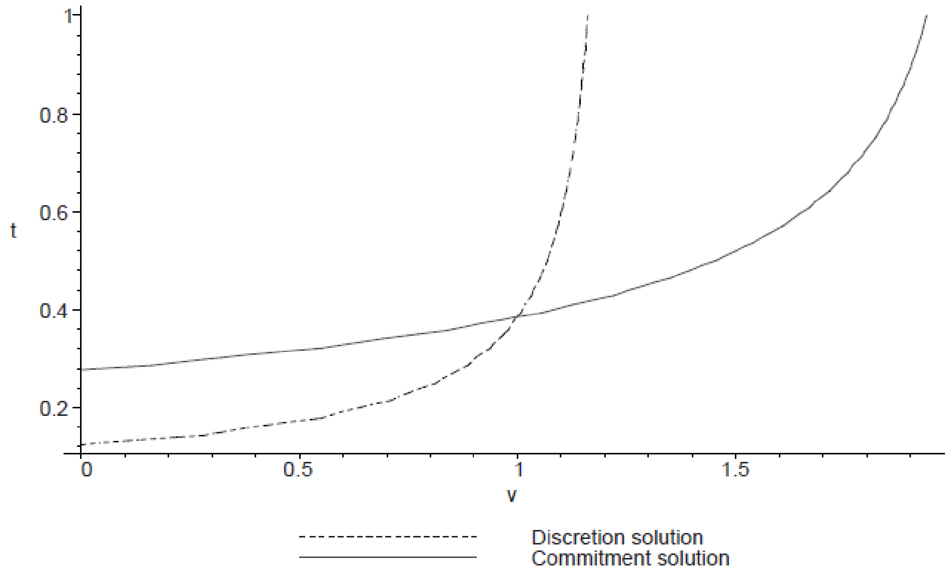
Helm *et al* (2004) proposes that this is dependent upon the value of ν, the marginal cost of public funds. This is the extra efficiency lost through raising the tax level. They state that if ν = 1 then the optimal tax is simply the marginal damage from emissions, $t = t^* = \lambda\gamma E^{\gamma-1}$, and that in this instance both discretion and commitment

[26] Helm *et al*, (2004) p9

solutions are equal. However, if ν > 1 then taxes are lower under commitment than discretion i.e. an *ex post* incentive to raise taxes, and vice versa for ν < 1. In practice it is not clear what value ν would take and this will be affected by a variety of considerations such as how distortionary the emissions tax is, how it reduces distortions in other taxes, distributional concerns and political economy factors. If a combination of these results in ν < 1, then discretion is not conducive to achieving credibility and therefore under-investment in low carbon technologies will occur. This is shown graphically in Figure 2.4.

The marginal cost of public funds is generally considered to be greater than one in the classical analysis, (Pigou, 1947; Browning, 1976), when there are distortions in the revenue raising process. However, this is not necessarily the case and other political considerations outside of the formal model will affect the marginal cost of public funds. Distributional concerns or political capture by fossil fuel lobbyists would incentive an *ex-post* reduction in the carbon tax.

Figure 2.4: Discretion and commitment emissions taxes for differing *v*



Source: Helm *et al* (2004)

Helm *et al* (2004) show that an additional policy instrument, in the form of an output subsidy, does not solve the problem under discretion and suggest institutional reform as a solution in the form of an independent energy agency. The model does seem a little over simplistic in so far as to suggest that a solution is completely dependent upon the marginal cost of public funds relative to the weight on emissions and consumer surplus.

Three possible forms of delegation are suggested as a solution to time inconsistency in this instance; (a) delegation of the true social welfare function, when reputation can be established and held, (b) an authority is given an instrument in order to achieve a single specific objective e.g. akin to the MPC, and (c) discretion given to an environmental policymaker that has a different weighting on emissions reduction, $\lambda \neq \lambda$, than that of society e.g. akin to the conservative central banker,.

2.4.5 Time inconsistency in monetary policy

There are many other areas of economics where problems of time inconsistency and credibility occur. The best known, classic, example is in monetary policy. Here a time inconsistency problem occurs because often government wishes to renege on low inflation promises for short term political gain by stimulating economic activity through cutting interest rates. However the public fully expects this and all the government achieves is larger than necessary inflation, an outcome that is generally labelled 'Inflation bias' (Barro and Gordon, 1983).[27] There are many possible solutions to this problem including committing to a rule, appointing a conservative central banker (Rogoff, 1985) or using an incentive contract (Walsh, 1995).[28]

In the case of monetary policy in the UK it is the Monetary Policy Committee (MPC) of the Bank of England, established in 1997 with a main remit of maintaining price stability. The MPC sets interest rates independently to achieve a government-determined inflation target, currently two percent. In this case we have so-called

[27] For a textbook analysis see Walsh (2003)
[28] See Kydland and Prescott (1977) on rules rather than discretion in general

‘instrument independence’ because there are two distinct bodies, one which sets the goal (government) and an independent body (MPC) tasked with carrying out the goal using a single policy instrument (the interest rate). The nine member committee publishes all of its monthly meeting minutes and has strict rules regarding how decisions are taken. These features create credibility and transparency to influence inflationary expectations where a time inconsistency problem would otherwise arise. In practice the MPC sets the interest rate as an instrument to indirectly control inflation and the public’s inflationary expectations. This has generally been seen as a success in the UK since its commencement in 1997 until the recent recession which began in late 2008. Therefore, for obvious reasons, the MPC solution tends to be viewed as a baseline against which other time inconsistency problems can be compared. This can be seen as providing a good argument for an independent climate change body that has an emissions tax as an instrument.

The monetary policy framework provides a remit for the MPC to a) maintain price stability; and b) subject to that, to support the economic policy of the government. Theoretically this could be construed as maximisation of a lexicographic welfare function, where the inflation rate is the first target and once achieved, the second task is the growth and employment rates. However, recent economic circumstances have shown that it is not always possible for the MPC to concentrate solely on influencing inflation expectations, especially when there is perceived to be a significant and serious threat to the real economy, and this is acknowledged in the monetary policy framework. In severe economic circumstances the MPC can cut interest rates in an attempt to stop deflation and also help stimulate spending when output drops substantially. Getting a consistent balance between the goals of inflation targeting and higher output levels is challenging. Recent events may well therefore affect the credibility of the MPC on inflation targeting, which will have to be re-earned over time, and so the MPC is probably less able to influence public inflationary expectations than before, an outcome that will remain until this credibility and belief that the MPC is committed to, and capable of, controlling inflation is regained over a period of relative stability in the economy.

Although an analysis of current UK monetary policy is not the purpose of this thesis, some further discussion aids the comparison with climate change policy and may give insight into future problems which could arise. The recent recession is the first time that the MPC has had to operate under such turbulent economic conditions. How exactly do these conditions affect the normal transmission mechanism, and is it only a temporary shift from business as usual? This raises the possibility that the MPC may have two separate functions and may work differently under distinct economic conditions. This is hinted at in the MPC remit, which states that it is responsible for hitting the government inflation target and subject to that, to also promote government economic policy of growth and employment.

The first function is under stable economic conditions, where the MPC is solely tasked with achieving price stability through the setting of interest rates to minimise variations of inflation around a two percent target. Here the task of supporting government economic policy on growth and employment is always secondary.

The second function, under difficult economic conditions, would be as a direct arm of government when the economy is subject to major shocks, while still keeping the objective of meeting the inflation target. Basically here the second objective, of supporting economic policy, may increase significantly in importance, especially when faced with the impending collapse of the financial system. However, it does not seem that the time inconsistency problem is always being solved if both objectives change in importance. This suggests that the theoretical removal of monetary policy from the political sphere is not entirely possible in practice: circumstances in which monetary policy has to adjust to avoid disaster in the real economy. This is not to diminish the success or benefits of the MPC but merely to suggest that it is not possible to sustain inflation goals in exceptional circumstances.

It is likely that, while the MPC is still attempting to control inflation, the transmission mechanism to do so does not function in the same way under difficult economic conditions. We can see this from the major adjustments in interest rates down to half a percent in March 2009. Inflationary expectations may have become more volatile or do not respond in the same manner as before. This might be due to a perceived change in what the interest rate is being used for, or in how other factors influence inflationary expectations. It is likely that this is only a temporary deviation and that the role of the base interest rate to, first and foremost, control inflation will eventually be reinstated. This is not the only extreme measure or deviation from the norm; we have seen quantitative easing used for the first time in the UK as a method for stimulating economic activity. The MPC took this step even though it increased the probability of missing the inflation target because they have been more concerned with the larger long-term ramifications of a possible collapse of the financial sector. The Monetary Policy framework does allow for government to instruct the setting of interest rates in extreme circumstances through other legislation; however this power has never been used. As for why it has never been used; perhaps the MPC has always anticipated its use by government and decided that it is better for the MPC to change its priorities, from setting interest rates for price stability to, instead, stimulating the economy, rather than letting the government take over. If the government was to use this power it would risk losing the credibility the MPC has acquired as a body. Therefore the question comes down to whether in a crises it is best for the MPC or the government to have control of an instrument which can help boost the economy.

Returning to climate change, a possible solution to the carbon policy time inconsistency problem would therefore be an independent body with a policy instrument similar to that of the MPC. The most likely and effective instrument would be the control of a price instrument in the form of a fiscally neutral carbon tax, which the body can alter to achieve the desired emission reduction target. An alternative would be a quantity based mechanism, such as emissions trading, as this would also raise fiscal revenue if allowances are wholly auctioned.[29] The fiscal neutrality of a tax or auctioned allowances is important in minimising distortions with government macroeconomic management (Pearce, 1991). Although in theory taxes would seem the better option with climate change due to steep marginal abatement curves and relatively flat marginal benefits, in practice quantity

[29] The implications of such a framework could be explored through further work with dynamic computable general equilibrium modelling.

mechanisms such as emissions trading have proven more popular.[30] This preference for quantity mechanisms is due to political and industry acceptance of permits over taxes, in part explained by the use of grandfathering as a method of issuing emissions allowances, especially if some or all permits are distributed for free, therefore essentially a one-off subsidy to existing industries. Also given that an aggregate emissions cap is necessary in climate change, quantity mechanisms make sense. If applied to tackle climate change, a carbon tax would quite definitely directly affect emissions expectations by incorporating carbon emissions into decisions with price certainty. In times of comparative tranquillity it may function similarly to the MPC as its commitment to a low carbon economy will be credible. However such a body may wish to alter this tax rate in times of economic turbulence if it has other considerations beyond tackling climate change or if updated science suggests changing emissions reductions targets. However, by ensuring that any such tax is fiscally neutral, variations in its level will, to a first approximation, not affect aggregate demand. To ensure fiscal neutrality is difficult however without the introduction of some monitoring of government decisions and in practice such taxes are rarely hypothecated in such a straightforward manner.

Helm and Hepburn (2007) also propose another possible solution to the time inconsistency issue. They suggest that long term carbon contracts could be used to move the risk involved in paying for reductions from investors to government, who are better placed to handle the risk, thereby lowering the cost of capital. This solution is perhaps analogous to the 'optimal contract' solution in monetary policy provided by Walsh (1995). It involves the government auctioning off long-term contracts to private companies, to provide certain amounts of future emissions reductions. This is only paid out on completion of the stipulated reduction being fulfilled. Essentially companies bid prices for specific emissions reduction levels, and the government then contracts with the company who can provide the reduction at least cost. This provides the long-run credibility, and carbon price certainty, needed over the life-cycle of investments in low-carbon technologies.

[30] The relative merits of price versus quantity instruments are outlined in Weitzman (1974). Benefits of price instruments has had extensive coverage in the literature on climate change market mechanisms, see Newell and Pizer (2003)

This method also has several advantages over a policy instruments, such as a carbon tax. Firstly, it establishes a legal credibility for investment in that “the auction for carbon reductions creates property rights which it will be very hard for subsequent politicians to unwind”.[31] Secondly, it allows flexibility in that the government can auction any amount of its total domestic emissions reduction target i.e. it does not have to auction the whole reduction it’s trying to achieve. Thirdly, an extra benefit of this method is that it clearly avoids the government “picking winners” in terms of technology adoption; it simply allows the market to choose the most efficient production mix. Unlike normal subsidy regimes these contracts simply allow the market to decide what technologies are employed to achieve the contracted reductions in emissions. There are many specifics of the auctions which would have to be decided upon however, such as; who can bid, frequency of auctions and what type of auction is used. In particular it would be sensible to hold such auctions during a period where there are required capacity replacements in the provision of energy to facilitate the move towards low-carbon energy. The permitted bidders in the auction would likely vary depending upon the portion of the national emissions target that was auctioned which could be anywhere between zero and the entire target. For instance, if only 20% of the target was auctioned then perhaps only installations from the energy sector would be allowed to participate. This may be beneficial if future international agreements do not come to fruition and the UK national emissions reduction target is lowered.

A similar proposal using long-term contracts, regarding the uptake of renewables called Contracts for difference (CfD), will be introduced in 2017 through the Energy Act (2012) as part of the Green Deal. The CfD scheme will replace the Renewables Obligation (RO) and as such remove the risk associated with volatility of the electricity price. This is achieved by setting a strike price where generators receive (pay) suppliers the difference between the strike price and the market price when the former is greater (smaller). Such contracting for carbon reductions would be more difficult to model using a Computable General Equilibrium framework, as costs

[31] Helm (2007b) p.13

would not be passed directly on to consumers through increased prices and therefore are not considered in the following chapters of the thesis. However, due to the many potential benefits further research on the merits of carbon contracts should be undertaken in future.

3. COMPOSITION AND ROLE OF THE CCC

Climate change really began to climb up the political agenda after the 2005 general election in the UK. Tony Blair mentioned tackling it as an important commitment in a speech in 2004 which led to political activism in the form of the Big Ask campaign from Friends of the Earth and the Stop Climate Chaos Coalition of over a hundred NGOs. Also, when David Cameron was voted to lead his party he used green campaigning as a way of rebranding the Conservatives as a more modern and fresh-thinking party (Institute for Government, 2010). In fact, the earliest political mention, in 2005, of a CCC-type body was David Cameron suggesting an independent monitoring Carbon Audit Office, which would provide a similar monitoring and forecasting role as the Monetary Policy Committee, should be created to examine British performance on tackling climate change (Independent, 2005). There had also been two important reports, there was the influential Stern Report on the *Economics of Climate Change* (Stern, 2006) and also Bryony Worthington’s response to the Climate Change Programme Review (Friends of the Earth, 2005) which was critical of long-term targets and stressed the need for reduction pathways as essential to achieve reduction targets. Then in September 2006 David Cameron and Friends of the Earth made a speech calling for a Climate Change Bill to be included in the Queen’s speech. This proposal was given support by the Liberal Democrats and the Labour party, who were in power, therefore felt they could not be the only party not supporting such a Bill. This essentially enabled the cross-party support to pass such legislation. David Miliband had been made Secretary of State at DEFRA in May 2006 and he setup an Office on Climate Change who drafted the Climate Change Bill which included multi-year targets overseen by an independent committee which would operate as a compliance mechanism. The creation of a Committee on Climate Change was then included in the draft Climate Change Bill in 2007.

The Climate Change Act was given royal assent in November 2008.[32] It provides for the creation of an independent, non-governmental body on climate change.[33] The CCC can have between 5 and 8 members plus a chair and chief executive to oversee its running. Committee members are experts in the fields of climate change science, policy, economics and technology. Currently these are Rt. Hon John Gummer, Lord Deben (Chair), David Kennedy (Chief Executive), Professor Samuel Fankhauser, Professor Sir Brian Hoskins, Professor Dame Julia King, Professor Lord May, Professor Jim Skea, Lord Krebs and Paul Johnston.[34] All of whom are appointed by the Secretary of State for Energy and Climate Change. These experts, mostly from an academic background, work to provide in-depth analysis and make decisions on climate change issues with a view to proposing the necessary steps to achieve a low-carbon UK economy. However, although they do detail specific policies available to achieve reductions in certain sectors, it is not within their remit to suggest the best policy approach to take; this is left to government. Obviously there is a need to have experts from different fields relating to climate change to gain the best perspective on how to tackle the problem and, given the wide-ranging considerations of the Committee (see Section 5.2 below on *extra considerations*), it is absolutely necessary to have members with a range of knowledge and expertise. The Committee currently meet once every three weeks and minutes of these meetings are publicly available. The minutes give an overview of all topics discussed and decisions made but do not detail any decision making processes. The Committee is supported by a staff to carry out the detailed analytical work.[35]

Details of all CCC recommendations are presented to Parliament and made available to the public to ensure transparency. The procedures on decision making are very open although there is a provision for anonymity where freedom of discussion would otherwise be limited. Whether this intended transparency occurs in practice will only

[32] The CCC had been in operation since February 2008 as a shadow body, which is why they were able to release their first report on the day they were officially created.
[33] The Act also merged departments within DEFRA and BERR to form the Department of Energy and Climate Change (DECC) whose Secretary of State is responsible for the CCC.
[34] Previous members include Lord Adair Turner (chair) and Professor Michael Grubb.
[35] The CCC is jointly funded by the UK and devolved administrations and employs its own secretariat of 30 staff.

become apparent in due course. The government then uses the CCC's advice when it announces the carbon budget in tandem with its annual fiscal budget. These carbon budgets detail exactly the amount of GHGs that can be emitted in the whole UK economy over a certain period. These are budgeted entirely on production-based methodology, and are detailed further below. The CCC must present an annual status report to Parliament on how the government is progressing towards the carbon budgets, to which the government must also respond.

The CCC was initially tasked in 2008 with advising the government on the following areas (see Table A1 of Appendix A for an overview):

(i) The 2050 UK target emissions level

The CCC provides a recommendation on the appropriate long-run emissions level for the UK. In reaching this recommended target, the CCC looks first at what global temperature stabilisation should be aimed for in 2100, estimating the effects of different temperature-increase scenarios. The stabilised global temperature suggested is $2C^0$ above 1900 levels. From this agreed temperature the CCC then identify the corresponding, globally stable level of emissions. After this they set a global long-term target for 2050 from which they are then able to set a UK 2050 target as a proportion of this, taking into account burden-sharing methodologies, international agreements and a technology vision for the UK. This process encompasses the principle of 'common but differentiated responsibility' and convergence of emissions per capita throughout the world.[36] The basis for these decisions is made public in order to give transparency to the process. All of this is a huge task in itself but is a necessary precursor to informing any UK level analysis.

The 2050 UK target set by the CCC in December 2008 is an 80% reduction below 1990 emissions levels. This is an increase from the Government's original 60% target (Stern, 2006) and was adopted in response to updated scientific evidence on the potential impacts of climate change, and also the realisation that recent concentrations of GHGs have proved to be higher than previously thought.

[36] This seems to imply a convergence in consumption per capita throughout the world in the long-run i.e equal emissions per capita by 2050 Stern (2009) states that average emissions of two tonnes CO_2 per capita worldwide would be required eventually to make the required reductions.

(ii) Carbon budgets for the periods 2008-12, 2013-17, 2018-22

The CCC also recommend to government medium term reductions in the form of 5-year carbon budgets which assist in achieving credibility, compared to the alternative of having a single, long-term target for 2050. There is a legally binding requirement that the 2018-22 GHG budget must be 26% below the 1990 emissions level. Points (iii) and (vi) below will also be considered as part of these budgets and the CCC will set out a trajectory to 2020 based on many considerations, including an estimated carbon price. These 5 year budgets should be setting the emissions path towards achieving the 2050 target. In their first report, the CCC has proposed an Interim Budget of a 34% reduction in emissions by 2020 compared to 1990 levels, which should apply if no global deal is reached. They have stated however, that if a global deal is reached, a more stringent Intended Budget, of a 42% reduction should apply to the UK by 2020, as more reductions could be achieved through tightening of the EU ETS allocation and global market mechanisms such as emissions trading and CDM projects (CCC, 2008b).[37]

(iii) Within these budgets the relative contribution of traded versus non-traded sectors needs to be identified

Currently around 50% of the UK's carbon emissions are covered by the EU ETS. The CCC must consider the relative split in the budgets between those sectors covered by emissions trading and those not covered under any trading scheme, which are likely to require different policy solutions. [38] This is of particular importance to achieving reductions at minimum cost and a major issue is whether domestically produced carbon which is part of the EU ETS should be included in the CCC budgets. This will be discussed further in sections 4 and 5.

[37] The Interim budget is based upon a 20% EU reduction with no international agreement and the Intended budget is based upon a 30% EU reduction with an international agreement in place.

[38] The sectors covered by the EU ETS are generally referred to as the 'traded sector'. This is not to be confused with the distinction between traded and non-traded goods, which depends simply on whether the good in question is traded across national (or regional) boundaries.

(iv) The inclusion of international shipping and aviation

The CCC analyse how important the inclusion of shipping and aviation is in lowering UK emissions, how much these sectors should contribute, as well as the practicality, methodology and timing of their inclusion. It was decided that these should be considered but not formally as part of first budgets. The CCC produced an Aviation report (CCC, 2009b) specifically discussing the main issues in that sector. The Scottish government is also currently considering how formally to incorporate these sectors into its targets[39]. Obviously this will be an area of some contention but its inclusion is imperative at some stage given the increasing demand for air travel and shipping due to globalisation and the global nature of climate change. Aviation will be included in the EU ETS from 2012 and sector-specific international agreements may be necessary for these given their unique nature and international scale. In its 4th Carbon Budget report the CCC have recommend incorporating international aviation and shipping into the budgets and will be considering further how this should be done (CCC, 2010b).

(v) Whether to include all GHGs in the above budgets

Given that Kyoto commitments relate to GHGs as a whole, but the EU ETS only covers CO_2, there seems to be a need to decide on the precise definition of what emissions are included within the CCC budgets. The CCC initial report decided that all GHGs should be part of the budgets and targets because: all GHGs contribute to climate change (some more so than others e.g. methane has a global warming potential 21 times that of CO_2); UK Kyoto commitments are listed in terms of GHGs, and the inclusion of more gases allows greater flexibility in achieving targets. This, however, raises fairly complex issues concerning the tracking of all GHGs and the likely impact of some policies, like the EU ETS, which only target certain GHGs. The CCC sees potential for non-CO_2 abatement opportunities in agriculture and waste, as well as possibilities in forestry. They stress that more work needs to be done before putting a policy framework in place for agriculture.

[39] See Climate Change Act Scotland (2009)

(vi) Extent of reliance on credits used to achieve targets/budgets

Recommendations must be given on whether credits from Kyoto flexible mechanisms such as Certified Emissions Reductions (CERs) from the Clean Development Mechanism (CDM) should be purchased in order to achieve the domestic emission reduction targets by cutting emissions in developing countries with lower abatement costs. These can be purchased directly through projects or through the EU ETS and Kyoto credits will tend to be cheaper than European Allowance Units (EAUs). This offers a more cost effective alternative to cutting domestic emissions, but seems at odds with the notion that countries should take full responsibility for their own actions, and that the UK should take a lead by providing an example for others to follow.[40]

However the CCC must also take the following issues into account when making any carbon budget recommendations (see Table A2 of Appendix A for overview):

- *Competitiveness Issues*

The CCC must consider which industries are potentially at risk, what policy regimes might affect marginal costs, the scale of possible effects and how these can be combated.

- *Fuel Poverty*

The CCC models the impact of carbon budgets on different households with particular concern for lower income households and look at what present and possible policies may be appropriate to reduce the negative effects that carbon budgets may have.

- *Fiscal resources*

This should take auctioning of allowances into account i.e. double dividend, which can be used for revenue recycling. Also there are fiscal implications for government expenditure of possibly purchasing Kyoto credits to meet targets. More generally

[40] The CCC suggested that no credits should be purchased under the Interim budget and the government has agreed to follow this recommendation.

they must also consider whether taxed activities will change in volume and whether alternative fiscal instruments are required to achieve goals.

- *Security of Supply*

This mostly concerns the risks attached to different energy forms and combinations as well as the capacity of the electricity grid and supply to meet energy demands. In particular the intermittent nature of renewables and their transmission to the network/grid is a concern as well as how international politics affects dependency on foreign energy imports. The benefits of a diverse portfolio of energy sources must be a consideration in this context (Awerbuch, 2000). Relying too heavily on one source of energy has limitations e.g. open to oil price shocks or exogenous political influence, and so risk can be minimised through appropriate diversification of available technologies.

- *Regional effects*

The CCC will disaggregate their budgets for separate parts of the UK and look at non-traded sectors for devolved authorities which have their own policy mechanisms. A coordination of policies would ideally be required here to achieve the most efficient outcome at a UK level and the CCC will offer guidance to regional administrations.

In December 2010 the CCC released its 4th Budget report detailing the necessary emissions reductions for the period 2023-2027. The main conclusion of the committee is that by 2030 there should be a reduction of emissions by 60% compared to 1990 levels. They also recommend a tightening of the 2nd and 3rd Budgets, in particular making the non-traded sector targets in line with the stricter "Intended" budget. This would give a 2020 target of a 37% emissions reduction from 1990 levels.

An adaptation advisory sub-committee on climate change (ASC) has also been created under the Climate Change Act, which is responsible for advising government on measures of adaptation necessary in the UK. Obviously the work on mitigation and adaptation are closely linked and the ASC will work closely with the CCC on many areas. The ASC has three main objectives (CCC Adaptation sub-committee, 2010). Firstly to oversee the development of the first Climate Change Risk Assessment (CCRA), a government report on the impacts which climate change may have in the UK, which must be produced before January 2012 and subsequently every five years. The ASC will provide advice for the CCRA throughout the period up until six months before the report is due. Secondly, the ASC must 'assess the preparedness of the UK to meet climate change risks and opportunities' by monitoring government progress towards meeting the objectives of the CCRA. This will involve progress reports being submitted in a similar procedure to that of the CCC. Thirdly, it is given the broad ranging task of promoting effective adaptation by all society through working with stakeholders and encouraging discussion on what steps can be taken in adaptation.

4. WHICH MODEL BEST FITS THE CCC?

It is productive to enquire which model best captures the CCC as an institution by comparing the CCC with each possible motive for its establishment that were outlined in Section 2. I start with an evaluation which assesses the CCC as a potential solution to the time inconsistency problem and move on to discuss the information provision, advisory and monitoring functions separately. I then consider specific issues concerning the setting of carbon budgets, extra considerations and policy interaction.

4.1 Time Inconsistency and comparison with the Monetary Policy Committee

Helm *et al* (2004) proposed an institutional change to solve time inconsistency in carbon policy and gave three possible options for an energy institution: a) one with a delegated welfare function, b) a conservative-central-banker-type climate change agency and c) an MPC-type agency with control over a policy instrument.

It would be interesting to know if the CCC is maximising a welfare function and what the arguments and composition of such a function would be. Here the government would ask the CCC to maximise a specific welfare function. Given the many factors the CCC is required to take into account, a welfare function could presumably include all of these, with weightings that indicate the relative importance of different objectives. However, it seems clear that the CCC has not in fact been delegated a welfare function, and in any case it has no way of setting or controlling policies though it can influence them. While a welfare function could be used as the basis for the CCC recommendations there is no reference to this. Perhaps the CCC could be viewed as strongly influencing or setting the government energy-welfare function through the carbon budgets, but if so, it is clearly implicit. Not revealing a welfare function where one actually guided the CCC's recommendations would certainly go against the principle of transparency on which the CCC clearly depends for creating credibility.

A more specific welfare function would apply if the CCC represented a body analogous to the 'conservative central banker' solution in monetary policy. This would involve delegating a welfare function to an institution which attaches a heavy weight to reducing emissions, perhaps by appointing members with a strong environmental background. Given the emphasis of the CCC on mitigating climate change, it seems likely that they weight emissions reductions at least as much, and probably more, highly than the government. This suggestion is consistent with the CCC announcement that the 2050 target should be at least an 80% reduction from 1990 levels, which led the government to alter its previous 60% reduction target. However, this shift reflects a scientific judgement rather than environmental preference – CCC take a decision on a target temperature and the emissions reductions needed to achieve this. Then detailed advice on how the necessary emissions reduction can be achieved is provided. It therefore appears to be the science and not the committee members' preferences that mainly drive decisions in the CCC, at least in this instance. There are areas that do require members to make decisions based upon judgement and not science, such as deciding on a methodology to apply in choosing a reasonable UK share of worldwide emissions reductions.

The final possibility is the solution outlined by Helm *et al* (2004) in which an institution is given a policy instrument to achieve a single objective – akin to the solution favoured in monetary policy. In all likeliness it seems that the MPC has been the political and theoretical inspiration for the creation of the CCC given that it was seen as a tried and tested method for solving time inconsistency:

"In economic policy, everyone can see that independence for the Bank of England has worked.... We now need Gordon Brown to understand the need for a 'Bank of England moment' when it comes to climate change"[41]

This quote from David Cameron in 2007, although obviously not reflecting the views of the government of the time, illustrates that the general political motivation and momentum in parliament for an independent committee on climate change, seems to be strongly linked to the idea of time inconsistency and the analogy with the MPC.

There are similarities between the MPC and the CCC. Both have a strong, forward-looking remit which involves technical decisions made by expert members within a transparent process, or at least a process that is declared to become transparent in the case of CCC, through the use of publicly available minutes. Each of these institutions uses the current evidence at their disposal to formulate projections of future outcomes and attempts to influence future expectations. They are even similar in that both have to use their expertise to come to a decision on precise quantitative changes: the change in the base interest rate and the government carbon budget relative to a BAU comparison. Also both have flexibility incorporated in to their process; the CCC recommends carbon budgets to be met over a *five year period*, and the MPC is allowed to deviate 1% either side of its inflation target before sanctions are imposed. The independence of both bodies is strongly stressed as necessary to fulfil their remit and essential to tackle the problem they are addressing and therefore

[41] Cameron, D., (2007), "We will keep up the pressure on climate change", Green Economy Conference [Speech], 12/03/2007

neither body is staffed by government employees. However, there are several major differences between the CCC and the MPC in terms of the problem they are solving and also in their operation.

4.1.1 Time Scale

The time scale of the problems being tackled in monetary and carbon policy differ significantly. Any analysis of the economy over time is heavily dependent upon what theory of expectations is adopted. Both monetary and carbon policy are trying to manage expectations but may use different discount rates in their analysis and approaches to modelling. With monetary policy, expectations typically relate to a shorter time frame, and influence both short and long-term investments. It is said that changes in interest rates will generally take two years to have an effect on inflation. However, the time inconsistency problem faced in the context of carbon policy relates to a much longer time scale, which includes considerations, at least in principle, of the welfare of generations quite some considerable time in the future. Some climate change analysis has tended to use discount rates which are lower than most prevailing interest rates or social discount rates used in public-sector cost benefit analyses.[42] Most private sector decisions will relate to expectations over the life-cycle of investments. With renewables this may be considerably longer than most investments e.g. 20-30 years for a wind farm or even longer for a nuclear power plant. The long-lived nature of such assets means that decisions on new energy investment tend to only occur when the assets require to be replaced or new supply is needed. The government in this instance is trying to influence expectations of carbon emissions decades into the future. Feedback is also a lot faster for the MPC than the CCC as it can observe its influence in a relatively short time frame and can do so through a very clear indicator, namely the returns on inflation-indexed bonds. So there is real-time feedback available for the MPC on their goal. Although the CCC will be able to view whether emissions have been reduced in years following the

[42] Stern (2006) used a discount rate of around 1.4%.

budgets, it will take decades for the CCC to notice if their work has actually made a difference to the goal of mitigating climate change.

In this instance carbon policy perhaps has more in common with the oil industry which also requires a certain amount of credibility for investment to take place. The oil industry it is open to similar time inconsistency with investments undertaken over a similar time frame and is therefore similarly taxed and regulated by government. Oil too is potentially exposed to large price variations over time and so future markets have developed. Companies seem happy to make risky investments in oil exploration and extraction, but not so with renewables to the same extent. However, a difference is that the many renewable technologies are dependent upon government support in order currently to make them competitive whereas the oil sector has been operating for a long time. Given the central role oil has played in the worldwide economy over the previous century, the heavy dependence of our infrastructure upon it means there is therefore an inelastic demand for oil. If infrastructure changes this may change in the not too distant future if renewable energy sources replace oil in countries energy mix.

The time scale of decision making for each body also differs. The MPC updates its decisions using a variety of evidence on new data and estimated future trends on a monthly basis, as this is what is necessary for monetary policy. The CCC reports annually to parliament and also produces reports on specific areas when requested by the Government as it has a statutory obligation to do so. Each report the CCC makes entails many months of in-depth preparation. This lengthy process is due to the technical differences involved, which are now considered.

4.1.2 Technical differences

A framework for comparative policy analysis involves looking at the instrument-target-goal relationship for any policy area. An instrument is used to achieve a desired goal; however normally this goal is difficult to accurately measure and therefore a target is generally used as an approximation or indicator for the final policy goal.

Both the CCC and MPC have to agree on a decision of a specific quantitative change. For the CCC this is a carbon budget, i.e. a change in the desired level of emissions. For the MPC the decision is a change in the level of the interest rate. The CCC's decision relates to a change in a policy *target,* and the MPC's relates to a change in a policy *instrument*. However, the decisions made by the bodies are reached through dramatically different processes.

The relationship between variables is significantly more complex with climate change than is the case with monetary policy. There is substantial empirical evidence relating the instrument-target-goal relationship in monetary policy. There is a relationship between the instrument (interest rate) and target (inflation) that has been long established, and although not certain in timing and degree, a clear chain of causality exists, at least out-with financial crises. There is also then a link between the target and the ultimate goal, which in this case is price stability. As stated above it generally takes a year or two for a monetary change to manifest itself in the economy. There is considerably less certainty in the transmission mechanisms involved in how emissions reduction targets directly affect climate change (goal). With climate policy, given the life of CO_2 in the atmosphere, a change in emissions may take a century to affect temperature – so the effect of making emissions reductions now cannot be witnessed until considerably later. There is therefore much greater uncertainty over how the climate system works and over the transmission mechanisms that relate policy instruments to policy goals, than is the case with the MPC. Also the policy goal is global, and therefore it is difficult to gauge whether the national targets are actually affecting this goal. Though, as recent events have demonstrated, our understanding of these linkages, even in the case of monetary policy, is perhaps not as good as had been believed.

One problem with setting an emissions target is that it is based, in part, on ambiguous equity considerations: these inform the decision on an "appropriate" UK share of total world emissions. The CCC currently uses a combination of burden-sharing methodologies to decide upon an appropriate UK share of global reductions and costs.[43] Here there is evidently an element of moral decision making which does not appear in monetary policy. Almost everyone benefits from stable inflation, and the government only benefit (from increasing inflation) in the short term but with a risk of losing credibility. However, with climate change the groups which are affected are more heterogeneous, and some may be affected a lot more than others. There are inevitably some "losers" from climate change mitigation e.g. those dependent upon fossil-fuel-intensive production processes, and this can make efforts politically difficult. Given the large uncertainties and risk that exist in climate change, it seems that carbon policy should be influenced by the notion of the 'precautionary principle'[44], and therefore should be a more conservative body than the MPC, as monetary policy does not entail the same degree of uncertainty, nor the possibility of such extreme, irreversible outcomes.[45]

One specific difference between monetary and carbon policy is that of symmetry of the targets. In monetary policy the MPC has a symmetrical inflation target of 2% where the MPC must send a letter to the Chancellor of the Exchequer if the inflation rate deviates one percent either side of the target. However, a deviation either side of that is treated the same – above is not better than below, and vice-versa e.g. a 1% inflation rate is as incorrect as a 3% inflation rate. This allows for fluctuations either side of the 2% target. Climate change targets appear to be asymmetrical. It seems generally agreed that over-achieving is considerably better than under-achieving and success will often be judged upon the over-meeting of carbon budgets. In this sense it seems that climate change targets are asymmetrical. This may be related to the precautionary principle and shows an important difference between policies directed at inflation and those focussed on climate change. However, over-achieving may not,

[43] These include "per capita convergence", "common but differentiated convergence", "Multistage", "Triptych" and "Intensity". For details see CCC (2008b) chp. 1

[44] The precautionary principle is a legal argument often used in the making of policy. An interpretation is expressed in the UNFCCC Rio Declaration Principle 15 and states that "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

[45] Although, of course, there are numerous examples of disastrous monetary policy being adopted.

in fact, always be desirable as it may be at the expense of other policy goals such as economic growth e.g. the extra reduction in emissions may reflect a cut in output. This trade-off between growth and the environment considerably complicates the conduct of energy policy. Perhaps the “extra considerations” that CCC is charged to take into account is an acknowledgement of these difficulties in reconciling policies that may be at odds. The trade-off between these goals is discussed further in the Section 5.2 on *Extra Considerations.*

4.1.3 Compositional and Institutional setup

There are differences in the composition and rules relating to both bodies. The MPC has strict rules on voting for decision making, with a majority of the nine members required and each member has one vote. The governor has the last and therefore deciding vote. The CCC, however, does not seem to be as rigid in its approach as there is no voting process. There is no indication as to how each CCC member’s views are weighted throughout the process of reaching their carbon budget recommendations. It appears to be more of a team decision-making process for the CCC with informed moral judgements made along the way to a consensus. The amount of time that members spend working for these bodies also differs dramatically. MPC members spend three days a week working on MPC related business and there is a considerably secretariat of around ninety people employed to support the MPC’s work. This is in comparison to the CCC where members only work for two days a month and the CCC’s secretariat is considerably smaller. These differences in resources clearly show that the CCC and MPC cannot function in a similar manner.

Unlike the case of monetary policy, the CCC is not the only body involved in carbon policy. There are institutions that continue to operate after its creation, such as the Carbon Trust, the Energy Saving Trust and energy-policy-related institutions like the regulatory body Ofgem. Issues arise in certain cases due to the unspecified or overlapping remits of institutions, as agencies may be too narrow in scope to make sure all necessary considerations are covered by at least one body i.e. some important policy consideration may be missed. Alternatively, various institutions may be too broad in scope, possibly resulting in inefficiencies where two bodies have overlapping functions. During the 2008 recession it was at times unclear as to whether the MPC or the Financial Services Authority (FSA) was responsible for tasks. With energy institutions there seems to be much more overlap with many institutions doubling up on similar goals and needing to take other energy goals into consideration. This could possibly be beneficial to policy if it provides highlights differing views and competing ideas but this will only be positive if the overlap is intentional and all parties are aware of it. There has to be more clarification given to bodies, especially energy institutions, on what their exact remit is and this must be clearly expressed from the outset to them and the public.[46]

The CCC appears to have too many ancillary considerations, if they are genuinely to be taken into account, and for the CCC to be wholly effective in achieving its primary objective: tackling climate change. The creation of the CCC was an opportunity to tidy-up the energy institutional setup, by creating an institution specifically directly to tackle emissions reductions, and perhaps also security of supply, which is dealt with along with the CCC's extra considerations. Yet the numerous considerations seem only to add to the existing complexity and potential confusion. On energy policy in general Helm says:

"The objectives –and the underlying market failures-are multiple, and need multiple policies simultaneously applied to address them. The more objectives, the greater the number of instruments required and, crucially, there is a need to define the trade-offs between them."[47]

[46] For a more general discussion about the role of NDPBs in government and how changes could be made to improve their efficiency see Institute for Government (2010)
[47] Helm (2007a) p.21

4.1.4 Policy Instruments

The CCC has no obvious instrument with which to achieve goals: it has not been delegated instrument-independence the way the MPC has. In fact it is almost the exact inverse of the MPC in so far as it appears to be *setting* targets rather than being charged with *meeting* them. This seems strange given the likely importance of the MPC as a basis of a model for the CCC. However it may be that the government is viewing the setting of targets virtually as “instruments” in themselves or at least as a surrogate for a non-specified instrument. In practice the CCC’s five year carbon budgets could be viewed as the instruments used to influence short/medium run emissions expectations, and the fact that the budgets are legally binding should add credibility, therefore significantly influencing, if not setting, public emission expectations. The credibility of targets can be backed up by emphasising the negative outcome of not meeting the budgets. However, I feel that this view of target-setting as an instrument is unlikely ultimately to hold much weight. Firstly, CCC recommendations are not themselves legally binding. Secondly, if agreed budgets are not in fact met in practice and there is no instrument other than the budgets themselves, then the CCC has no means of ensuring that targets are met. Therefore the analogy with the MPC, while appearing in some very general sense to have underlain the creation of the CCC, does not in fact hold. It appears in practice that the carbon budgets are a framework situated above any policy instruments, and it is these carbon budgets which guide what policy instruments are appropriate. The carbon budgets therefore provide consistency and certainty to Government and its departments but not directly to businesses. This is done through various other Government policy instruments. I return to the concept of the CCC actually being delegated an instrument, such as a carbon tax, later on when discussing policy interaction and in future chapters. However, if multiple equilibria exist, with the government deciding between possible high and low temperatures as an equilibrium, then the announcement of targets may help achieve a stable outcome as the private sector will adjust their expectations and make decisions appropriately. Even when the MPC does not meet targets the credibility of the system still typically holds due to the reputation of the committee and also the transparency involved. The MPC were always able clearly to explain any deviations from inflation targets and put them into context in terms of the long-run path of the economy.

4.2 'Rolling Stern *plus*' model

In practice, it seems to us that the role of the CCC is in fact best viewed as an advisory 'Rolling Stern' model, which incorporates an additional monitoring function. Rather than being a delivery body of the government, the CCC appears to inform government policy and the delivery of the policy is achieved by government itself and through independent bodies such as the Carbon Trust. Scientific and economic advice on climate change has been provided in the recent past. In 2006 Lord Nicholas Stern, who was at the time head of the Government Economic Service, and his team, provided the British government with the most comprehensive review on the economics of climate change ever undertaken (Stern, 2006). The review was hotly debated and was generally heralded as a world-leading insight into climate change policy, discussing issues at both a national and international level. This report combined principles of science, economics and moral philosophy in order to arrive at a conclusion as to the extent of reductions needed. At a more general level the Stern review can be seen as an attempt to form a consensus on a target level for emissions reductions and therefore act as a reference point for both UK and international energy policy.

Since the Stern Review it has become clear that there is a need for this work to be continuously updated to provide more in-depth, timely advice on climate change to all interested parties. Due to the high levels of uncertainty involved with climate change our understanding of the science is constantly evolving. The changes in the science then inform developments in the economics of climate change, and government must be kept abreast of these changes when making policy. Given the complexity of the information, which may be manipulated by interest groups, it seems appropriate to have an independent advisory body that can provide advice on a continuing basis to the government on the necessary changes that need to be made.

This sort of ‘Rolling Stern’ body is the “model” of delegation that the CCC appears to be closest to. However, unlike Stern, the CCC is importantly a statutory body. In both its advisory and monitoring functions the CCC is a Non-Departmental Public Body and therefore must operate within any guidelines on NDPBs issued by the government. Technically the CCC is listed as an Executive NDPB because it employs its staff are employed independently i.e. they are not civil servants. More generally there has recently been some contention over the role that such bodies play within the political sphere and to what extent they are effective and truly independent.

The independence of the Advisory Council on the Misuse of Drugs was questioned in November 2009 after the Home Secretary Alan Johnson sacked the Council’s leader Professor Nutt for crossing a perceived line into politics. Professor Nutt had publicly stated in a lecture that the government’s decision to reclassify cannabis went against scientific evidence and was made purely for political purposes. The Home secretary felt that Professor Nutt had openly criticised government policy and duly dismissed him after “losing confidence” in his advice. A number of other council members resigned in protest and this incident has sparked much debate over how independent these advisory bodies can actually be and how government interprets scientific advice. The government responded quickly by issuing guidelines pertaining to how advisory bodies should function. Yet the recent events with the Drugs advisory council have perhaps changed this perception of how NDPBs are viewed. Government may choose not to follow the CCC’s advice but in such circumstances it runs the risk of severely damaging the reputation of the body it created, if no compelling reason can be given for going against the advice. The CCC however seems to be billed as more than just a NDPB. Instead it appears to be a body that would strongly influence policy and whose independence would be complete, much like the MPC. Both the Bank of England and the CCC are heavily enshrined in domestic legislation and therefore appear to carry more weight than regular NDPBs which can often be setup in an ad hoc manner. It is this statutory mandate that makes the CCC different to, and perhaps more powerful than, the work of Stern.

> "The essential task of the Committee can be summed up as providing advice on how fast the UK can and should progress towards a low-carbon economy and how it achieves that progress."[48]

The CCC can be seen as a "Rolling Stern *plus*" model because as well as work comparable to that undertaken by Stern, it also incorporates the monitoring role that was suggested by Helm *et al* (2003) as being the most likely UK outcome of a new institution for solution of the time inconsistency problem of carbon policy. These two roles, as an advisory body and also a monitoring body, make up the real remit of the CCC from the possibilities for delegation discussed in Section 2. This may still provide a degree of credibility for carbon policy to investors.

The composition of the body, in terms of its members, appears to be well judged in that it is mainly comprised of individuals from a strong academic background whose unbiased experience make them well placed to advise government on the many issues involved in climate change. The mix of well respected individuals should give the CCC the expertise, and hence credibility, it requires to fulfil its duties.

The incorporation of an adaptation sub-committee should also be welcomed as both mitigation and adaptation need to be considered in light of the science which suggests that some adaptation will be required in the UK. Therefore expert advice is needed to inform the government's strategy on adaptation. Changes in UK temperatures will affect many individuals and industries through increased droughts, flooding and extreme weather. Stern (2006) discusses the economics of adaptation, and explicitly incorporates modelling of it in the analysis. This sub-committee of the CCC can build on that to provide a detailed analysis of the relevant UK issues and could therefore be considered an additional "*plus*" in the "Rolling Stern *plus*" model.

The other possible reason for delegation outlined in Section 2 was "Information provision". The CCC does not seem to be fulfilling such a role. It is providing advice for the government but not directly to the population at large; public information is

[48] CCC (2008b), foreword p5

being disseminated by the government through various other channels. The CCC does provide yearly reports in parliament that must be responded to by the government. This information they are providing is public but it is not directed at the public. There may, however, be a need for information provision to the public from a reliable and trusted source.

In the lead up to Copenhagen in 2009 and beyond the science on climate change came under severe attack, especially after the so-called “Climategate” affair where numerous e-mails were leaked from researchers at the University of East Anglia pertaining to inaccuracies in data used in an IPCC report and also the holding back of data. The lack of transparency here was severely criticised by independent reviews.[49] Although the debacle was blown out of all proportion, it is an indication that public trust in the credibility of climate change information is very fragile and must be treated with due care. Perhaps an existing institution such as the Carbon Trust or Energy Saving Trust could take on this role as currently these bodies operate as separate entities to government, such delegation may be beneficial in preventing any potential data manipulation. However, an ‘information providing’ body would be required to work more closely with the CCC and government to ensure cohesion of information distributed and policy.

In summary, from the possible reasons for delegation outlined in Section 2, the CCC has not been created for information provision, except to Government, or for a policy delegation purpose; even though the latter is the most compelling in terms of its motivation. Instead the CCC has taken the form of advisory and monitoring body.

The next section evaluates many of the features of the CCC. In particular, issues surrounding the setting and implementation of carbon budgets, its extra considerations, monitoring functions and the interaction of the CCC budgets with other instruments and spatial levels.

[49] For one such independent review commissioned by the University of East Anglia see Russell (2010)

5. EVALUATION OF THE COMMITTEE ON CLIMATE CHANGE

5.1 Setting carbon budgets

There are still issues and questions surrounding the advisory nature of the CCC, mostly related to the setting of carbon budgets and whether the government always accepts the CCC's advice. In practice, the successful meeting of budgets is critically dependent on many external factors that are exogenous to the CCC (and to the government) such as the price of oil and the price of carbon within the EU ETS. The CCC has obviously incorporated this into its modelling but the extent to which these factors affect budgets may well make it difficult to meet them. The EU ETS carbon price, which covers roughly 50% of UK emissions, has fluctuated substantially since its inception in 2005.

Also, the condition of the world and UK economies will impact significantly upon whether short and medium-run budgets are actually met, and budgets may have to be adjusted for fluctuating economic circumstances. Economic growth and emissions are intrinsically linked, and there is most likely a trade-off between them. For example, at an international level the UK has found it comparatively easy to meet its Kyoto targets in part because of the decline in the UK coal and steel industries since 1990 and also the change in the price of gas making it relatively cheaper than coal. This then lead to a greater dependency on energy imports in the UK while domestic production has decreased. Meeting targets has been more likely down to circumstance rather than effective policy. There is, of course, no guarantee that events will act fortuitously to ensure the satisfaction of carbon budgets.

Also, in the same way that economic turbulence can affect monetary policy, it can also raise similar issues in carbon policy. There were calls for reducing targets because of the 2008 recession as firms were under enough pressure without having extra responsibility. Thankfully there have been encouraging signs that the CCC is looking long-term, as ex-chair Lord Turner has stated that the budgets will not be revised in light of the current recession. However, it must be noted that the budgets should be targeting the economy operating at 'full capacity' i.e. budgets should be explicitly predicated upon the long-term growth rate. In a recession it will actually be easier to meet emissions targets, therefore possible upward revisions may be necessary i.e. strengthening of earlier carbon budgets to achieve the longer term targets. This depends upon how budgets are expressed because due to the time GHGs stay in the atmosphere, it is important that targets are concerned with cumulative stocks of emissions rather than flows. As the change in temperature is a direct function of the stock of carbon (or equivalent) then any targets should themselves be in stock terms.

However, the downturn in economic activity will make it harder to fund future projects given reduced investment and higher government deficits. Shocks to the world economy may well severely affect projected growth rates and this may drastically alter underlying assumptions on which the budgets are based. Therefore the CCC must make informed judgements as to whether events are cyclical, and so should not alter their analysis, or whether an event shifts the path of the economy and therefore carbon budgets must be modified appropriately. All in all, there are multiple factors which may require the carbon budgets to be revised, and these factors may occur concurrently and in varying directions. The CCC is well aware of these issues and has very detailed analysis in place. Generally it is worth noting the extent to which key determinants of actual emissions are outside the direct control of the CCC and the UK Government.

It is also not clear what the government budgets being ‘legally binding’ really means in practice. It certainly conveys the impression of conviction, but to what extent does it genuinely boost credibility? If there is no actual legal challenge to the government not complying with the carbon budgets, then does having these budgets enshrined in legislation actually provide any additional credibility at all? Judicial review is a legal challenge to decisions of government bodies which have exceeded their own powers. If the targets are legally binding, this opens the possibility that the government could be legally challenged in court over non-compliance with meeting targets or taking decisions that undermine the achievement of targets. There are varying opinions on whether this is a real possibility as the government can change the targets themselves later anyway, but the extent to which this is done in practice will affect the credibility of the whole process and may partially undermine the CCC. However, in practice it is unlikely that any sort of judicial review of decisions on climate policy would be successful due to the strict application requirements and the political consequences of allowing the possibility of legal challenges.

There has been mention of legal action taken by Green groups on specific government decisions that may have significant implications on the ability to meet the carbon budgets, for example, the extension of Heathrow airport, new nuclear power plants and a potential new Forth Road Bridge. So far the only precedent has been a case regarding the extension of Heathrow airport where the judge ruled that the government must reconsider their decision to allow expansion as the full information was not known at time of the decision, and the CCC report was heavily cited throughout (Bowcott, 2010). Therefore it seems possible that the courts may legally oblige government to take decisions again but not actually decree a particular decision illegal and require government to justify their decision in light of new evidence. However, the fact that carbon budgets are enshrined in legislation does have some serious bearing on any possible amendments, where any order revoking or amending a carbon budget must be passed by affirmative resolution in Parliament. That is, changes require positive approval to be passed rather than automatically gaining approval unless it is disagreed with. This makes the budgets more difficult to alter in theory.

The frequency of budget setting is a trade-off between, on the one hand, trying to provide certainty for investors, which would be brought about by annual year-on-year targets (assuming there is confidence that they will be met) i.e. one year carbon budgets detailing in advance how much can be emitted each year for a given period. On the other hand, the benefits of flexibility and lower reporting burden of less frequent budgets. The concept of the five year carbon budgets was originally called for by Bryony Worthington who worked for Scottish and Southern Energy as well as heading Friends of the Earth’s Big Ask campaign (she is now a Labour peer in the House of lords for her work on climate change), who was brought in to help draft the

Climate Change Act. Many opposition MPs and environmentalists appeared to favour stricter targets but the budgets appeared to be adopted in order to allow flexibility. An issue with setting 5-year budgets is that the reduction is an average across that time period. However, as mentioned previously, the stock of carbon in the atmosphere is more important than the flow. Although, the setting of annual targets does not necessarily imply certainty; increased frequency may make it more difficult to consistently achieve targets. For example, if a nuclear station had to shut one year unexpectedly, then it would be necessary to rely on coal and gas to make up the difference and thus emissions would substantially increase for that single year.

The Scottish Climate Change Act has established the requirement of such yearly carbon budgets in Scotland. It will be interesting to see how these are set and met in comparison to the UK budgets, especially given Scotland's current dependence on a small number of large generators. The CCC's report to the Scottish Government (CCC, 2010a) has expressed concern with the lack of flexibility in the Scottish annual targets and suggests measures could be considered to increase flexibility, although it is not within their remit actually to recommend doing so. (I discuss the appropriate spatial scale for policy when comparing Scottish and UK climate change legislation in Appendix B).

The CCC has decided to include all GHGs in its budgets. Although CO_2 makes up most GHGs, roughly 85% of UK emissions in 2008, many of the others are more potent and dangerous for the environment. The CCC has called for the government to set out an agricultural climate change policy. They see this is as being slightly problematic due to the difficulty in collecting data in such a sparse sector as agriculture where measuring emissions may be onerous and costly. Including all GHGs will allow greater flexibility in reaching targets and is consistent with the UK's Kyoto targets although it will increase monitoring cost for government and the complexity of modelling for the CCC. However, CO_2 emissions have actually risen over the last ten years while non-CO_2 gases have dropped due to changes in industrial processes and agriculture, in particular methane emissions have significantly fallen from waste in landfill (CCC, 2008b). Therefore if trends continue this way, the reduction efforts will have to still be concentrated on curbing CO_2 emissions from growing too much, as in practice they contribute by far the most to causing climate change, while other GHGs may continue to decline.[50]

International aviation and shipping have not yet been included in the budgets although these transport sectors are of vital importance to the debate as they are an ever growing contributor to UK and worldwide GHG emissions. Deciding the method to be used to include these will be a near impossible task if they are to be done precisely and their inclusion could have large competitiveness impacts. The issue is mainly one of who takes responsibility for emissions. The CCC feels more effort and research is needed on this topic before these sectors can be accurately incorporated into the carbon budgets. The UK government has stated that its target is to allow aviation emissions in 2050 to be no higher than current levels. The CCC then produced an Aviation report in December 2009 that analysed projections in air travel and reached the conclusion that demand growth of 60% would be possible to achieve this given efficiency improvements and changes in fuel used and demand through appropriate policies (CCC, 2009b). This was against a likely business-as-usual scenario of a 200% increase. The CCC state that global aviation emissions must be capped through an international sectoral agreement or by incorporating aviation into other targets and markets e.g. Air travel will be included as part of the EU ETS from 1st January 2012.

How these emissions from either aviation or shipping are incorporated into budgets is difficult to decide upon. Emissions take place during travel between countries, so where should It would be possible to incorporate emissions from air travel and shipping on a consumption basis but this may be incredibly difficult to implement in practice. However, in practice introducing some rule of thumb is of course feasible e.g. emissions are split equally between origin and destination countries, and this is

[50] Also the comparison of including only CO_2 versus including all GHGs may have different impacts for specific regions and sectors which may heavily use other GHGs e.g. agriculture; therefore differing impacts are worth discussing and perhaps analysing within a computable general equilibrium framework.

much better than simply ignoring such emissions. Advice on the 4th carbon budget (CCC, 2010b) has called for international aviation and shipping to be included in future budgets and will soon produce advice on how the 2nd, 3rd and 4th budgets should be adjusted to incorporate these sectors.

More generally there is an issue in the UK regarding the use of production-based targets for domestic emissions reductions, which is also the methodology used by the UNFCCC. Currently the norm is for countries to account for their emissions based upon how much they produce within the country by summing the emissions from all domestic sources of production. However, this method completely disregards trade flows. If domestic production of energy-intensive goods moves elsewhere and these goods are then imported, the reduction in domestic emissions may make no contribution at all to combating global warming. Under a production measure such "carbon leakage" would give the impression that conditions have improved domestically, even if global warming is in fact unaffected. If UK domestic emissions from production decreases but is completely offset or perhaps even more than offset, by emissions leakage to other countries, since they may use even dirtier technologies, then this totally neglects the global nature of the problem being tackled. There is no point in the UK achieving an 80% reduction by 2050 if it does so entirely through displaced production but continued, or even increased, consumption levels. Also, given that the UK alone has a very minimal impact on climate change, then the argument for setting emissions reductions targets must be a mostly moral one. If this is the case then there is a strong argument for employing consumption-based accounting measures, to confirm that the UK's actions on climate change are indeed making a positive contribution and not merely appearing to.

Helm *et al* (2007) find that on a production basis there has been a 15% reduction in GHG emissions since 1990 but on a consumption basis over the same period, emissions have risen by 19% and there has been a divergence between production and consumption accounts over time.[51] This shows a very different picture of emissions to the one being portrayed by government, where UK emissions are

[51] Although their calculations were only a crude approximation and therefore should not be taken as definitive. A far more detailed analysis is required

supposedly decreasing using a production-based method. The CCC would be more effective as a climate change body if it simultaneously discussed the UK's emissions from a consumption perspective although this omission may be because it is not explicitly part of its remit.

Using consumption-based targets would, in principle at least, provide a more accurate reflection of emissions per capita. It would also likely be a stricter measure for developed nations although this depends upon the balance of trade (Helm *et al*, 2007). There is a trade-off to some extent because although consumption-based approaches may be more accurate, they are also more difficult to measure because of trade flows. Still, although measurement of consumption impacts is a more complex task than any production based analysis, it is not impossible and should be considered in parallel and steps should be taken to produce a range of measurements on UK emissions which would allow the CCC to monitor the movements of consumption and production indicators over time.[52] Stern (2009) argues that some worldwide convergence of consumption is needed if emissions are to be stabilised at the required levels. The CCC also has this view in its burden sharing methodologies. It therefore seems a significant limitation that the CCC, and more importantly any global agreement, neglects a consumption-based analysis of emissions. The CCC has an opportunity to establish that a consumption route is necessary in the long-run and that the UK can lead the way in establishing this path worldwide.

Personal carbon trading is a potential option highlighted by the CCC but needs further research and will likely be difficult to implement as it would entail high transaction costs. The CCC should look to begin establishing emissions accounting based upon consumption and how best to collect the necessary data, highlighting the difficulties involved and incorporating this into its monitoring function.[53] Getting detailed data on emissions intensity of all products imported and exported would be an enormous task and would require worldwide cooperation and coordination.

[52] For discussion of consumption- accounting methods see Davis and Calderia (2010) and also on environmental impact of consumption see Weidmann *et al* (2007). For comparison of producer vs. consumer responsibility see Munksgaard and Pedersen (2001).
[53] See Turner *et al* – parts 1 and 2 (2007a, b) for an overview of Input-Output attempts at consumption trade flows and McGregor *et al* (2008) for an attempt at Scottish vs. UK CO_2 trade flows

Therefore, these issues should be taken into consideration by government in formulating international policy. However short-cut methods do exist and should be used, at the very least to check for major divergence in production and consumption measurements over time. Helm (2009) suggests that a carbon tax should be employed which can also function as a border tax. It would tax the carbon/energy intensity of goods and would start off on goods which can be measured and become more inclusive over time. This would also create a price floor for carbon. Although the Project Discovery report by Ofgem highlights that this may prove difficult to implement as any national emissions tax will have to adhere to EU rules already in place (Ofgem, 2010). We return later to the possibility that the CCC could control such a tax as a policy instrument.

China seems to be adopting an alternative measurement of emissions by using carbon intensity of GDP as its reduction target. This is still a production based target and is therefore completely dependent upon growth of their economy. However a reduction in CO_2 intensity is quite consistent in a rapidly growing economy with an increase in CO_2 output. Having a production-based accounting method is however likelier to be tougher for China than a consumption-based method given that much of its emissions are currently for energy intensive exports to developed nations, although this may change over time as their standard of living and consumption rises.

5.2 Extra Considerations

If possible, it is potentially important to distinguish between the considerations that genuinely impact upon the CCC decisions and those that are part of the more formal requirements, but are likely to impact less in practice. Only time and evolution of the CCC is likely to establish which considerations are truly important and at the forefront of the decision making process in their reports. Even here it may be that the CCC's priorities may vary with conditions, so it may prove impossible to reveal its preferences through deduction from evidence of its actions. Hopefully, its transparency should solve this problem. Should the CCC merely report on the possible impacts to these areas of concern but refrain from actually adjusting their recommendations based on possible impacts? Obviously the CCC has to be mindful of constraints but it cannot be expected to put an equal weighting on all concerns. As mentioned earlier these extra considerations may represent an attempt to encourage CCC to recognise the linkages and interaction between various policy goals.

5.2.1 Competitiveness issues

This relates to both competitiveness issues within the UK and to competitiveness of the UK vs. rest of the world. Implications of carbon budgets may well affect the competiveness of certain sectors and so the CCC must be aware of what likely impacts may occur. Should the CCC only be commenting on the likely influence of its budget recommendations upon competitiveness of UK industries but not adjusting budgets downwards if negative effects are expected to be extensive? Perhaps though, at an international level, there is a bigger role for considering policies to maintain UK industry competitiveness. Overall the CCC sees no long-term competitiveness effects of carbon budgets, and the short term disadvantages only seriously affects a few industries which can be protected by appropriate policy levers.[54] Plus movement of industries to other countries may also cause carbon leakage. Any disadvantages will be offset in the longer term as the CCC does see potential for the UK having a competitive advantage in new industries such as wave and tidal energy which will compensate for any negative competitiveness effects.[55] The competitiveness of the energy sector within the UK is historically the main role of Ofgem which has established its main priority as protecting electricity consumers from exploitation by monopoly suppliers.[56] Any concerns on energy highlighted by the CCC will have to be communicated to and discussed with Ofgem to ensure consistency and cohesion within UK energy policy.

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[54] These few industries account for 1% of UK GDP and are regionally concentrated. Protection may come in the form of sectoral agreements or continuing free EU ETS allowances (CCC, 2008b: chapter 10)

[55] CCC take this from various sources including BERR (2008)

[56] Although recent outputs from Ofgem suggest a move towards broader concerns. See their recent Project Discovery (Ofgem, 2010)

5.2.2 Fuel Poverty

The CCC cannot be expected to tackle fuel poverty, especially given that the natural way to tackle this is via the tax – transfer system which is out-with the CCC control. Obviously it can comment upon the impact carbon budgets are likely to have upon the fuel poor and then advise the government accordingly. Ofgem still have responsibility for ensuring consumers are paying a fair price for their energy, so again working with them is a necessity. Government initiatives are often needed to help the worst off and elderly, who are most vulnerable. Through its modelling (designed by the Buildings Research Establishment) the CCC believes that electricity and gas price increases implied by the satisfaction of carbon budgets will impact heavily by increasing the number of fuel poor households by 1.7 million in 2020 which would cost £500 million a year to compensate for this increase.[57] They suggest the possibility of social tariffs and/or income transfers as policy measures to combat the increases but more clarity is needed on this important area as it is unlikely the Government will introduce policies that will be unpopular amongst the fuel poor.

5.2.3 Economic Costs and Fiscal Resources

The CCC will analyse what the likely macroeconomic costs are of implementing carbon budgets through higher energy costs, energy efficiency improvements, lifestyle changes and competitiveness impacts. They conclude that meeting the 2020 targets will cost less than 1% of GDP. The CCC also analysed the possible fiscal impacts of carbon budgets and concluded that a combination of positive and negative effects would likely occur e.g. EU ETS auction revenues but reduced fuel duty revenues due to the electrification of most transport. Fiscal neutrality must be responsibly implemented to minimise distortions. When analysing the impact of tax, it is essential to do so with fiscal adjustments implemented in a neutral way. (Of course, policy need not operate in this manner i.e. might want net additional tax to

[57] This is based upon various assumptions regarding electricity prices, gas prices, real disposable income and many more. See CCC (2008b) chapter 12

reduce borrowing. However, this is straying into macroeconomic policy and away from energy policy.)

5.2.4 Security of supply

Helm *et al* (2003) suggested that there should be an energy agency whose primary functions are climate change and security of supply, but there is no indication that the CCC should consider security of supply above any of the other ‘extra considerations’. In their report the CCC distinguish between ‘technical’ security of supply and ‘geopolitical and economic’ security of supply. The CCC considers that ‘technical’ security of supply i.e. ability to meet demand, will not be undermined by renewables provided that necessary back-up capacity is available. When considering ‘geopolitical and economic’ security of supply i.e. insulation from exogenous price shocks and political events, they believe increased penetration of low-carbon technologies to be beneficial but give no approximation as to the extent of this benefit. Portfolio theory suggests that the use of a range of renewables will be important in improving the diversity of energy sources and reducing risk.

5.2.5 Regional effects

The CCC can comment on possible regional effects of carbon budgets. For instance, it may be the case that Scotland becomes an exporter of renewable electricity given its renewable potential.[58] Also the Scottish Government currently has a “no nuclear” policy for electricity generating capacity in Scotland even though energy is a reserved matter. Will this have any impact on how carbon budgets can be met? More generally is it beneficial for the CCC to look at specific regions or is there a possibility of duplicate work with other administrations? Given that the Scottish government has passed its own Climate Change (Scotland) Act, requiring the setting

[58]Scotland is currently a net exporter of electricity, but over the coming years some plants will be decommissioned.

of annual carbon targets and allowing for the possibility of setting up a Scottish Climate Change Committee, are there any areas of contention?[59] Any complete regional analysis will need a model of that region. Also, at a local level Regional Development Agencies have responsibilities and targets for sustainable development. Therefore there are a whole set of issues relating to multi-level governance. The CCC initially highlights the steel industry in Wales as potentially being adversely affected by budgets.

The CCC has a lot to contemplate in analysing the extra considerations it has been tasked with commenting upon. Their findings must be taken aboard by government and updated as more information becomes available over time. Other institutions such as Ofgem and the Carbon Trust must be made fully aware of many of the findings regarding competition and technological advances.

5.3 Monitoring functions

It is too early to tell whether the monitoring role of the CCC will be effective but many essential components e.g. independence, are in place, hopefully to ensure that the credibility it aims to establish is realised. Without some monitoring body there would be little chance of credibility being established and this role is where the strength of the CCC may well lie. A similar monitoring body was the Sustainable Development Commission (SDC), which recently had its funding severely reduced and so no longer operates at a UK level. The SDC was another NDPB which provided advice to Government on how to be sustainable, as well as a watchdog function which required them to hold Government to account on their progress towards sustainable development indicators. It was intended to help all Government decisions be sustainable and hopefully make efficiency savings in the process.

[59] This is discussed in more depth in Appendix B

The CCC's first monitoring report to parliament in October 2009 (CCC, 2009a) has called for a step-change in climate change policy in order to achieve future targets. The first report has no official data yet for the first budget period, but using emissions data from 2003-2007 it has shown that emissions are only dropping at a rate of less than 1% per annum over this period. It has called for an increased policy effort to materialise a 'step-change' and raise reductions to between 2-3% a year. To achieve this it specifically suggests a new approach with regards to power generation, stating that the current combination of markets and instruments is not working and new policies as well as a review of existing ones will be required. It also suggests that the role of government in home energy efficiency needs to be stronger as well as introducing new incentives for renewable heat targets, take-up of electric vehicles and increased public transport use. This report has been interesting as it has highlighted that the CCC will not only be assessing progress but also be forward-looking in its monitoring role, checking for key indicators to show that budgets are on the required path to meet targets. There are indicators for the power sector, energy use in buildings and also transport.

This openness is to be welcomed because it should give investors valuable insight into the credibility of government policies and whether budgets are on track to be met. The first progress report to parliament also highlights how the recession has affected budgets and what should be done in response to it. They highlight that prices in the EU ETS have dropped significantly which may affect incentives to invest in low-carbon technologies. The CCC therefore recommends that the government aims to outperform the first budget and highlights that the current EU ETS carbon price cannot be relied upon to achieve the necessary emissions reductions. It also states that any outperformance of budgets should not be banked in future periods. Again this is to be commended as it shows the CCC is seeking to take into consideration those factors that will impact upon the carbon budgets while still focusing on longer-term targets. They seem to accept that although it is important to have flexibility in meeting targets, the cumulative emissions in the atmosphere are what essentially matters. Therefore any one-off external factor that influences emission levels should not be counted because it is the emissions path taken by the economy over time which will actually determine whether the cumulative target is achieved. We can't rely on recessions in helping us achieve our climate change goals.

Government must respond to the CCC yearly monitoring report in parliament, this is a statutory requirement and opens the Government to possible criticism and the need to explain their actions. Only in a few years, once we have seen whether the government has truly taken on board the CCC's advice, will we be able to evaluate its significance. Also, the timing of the budgets - every five years - means that many current MPs may not hold office when the budget they set now is intended to be met. It is therefore imperative that the yearly monitoring reports of the CCC are detailed, commenting on whether or not they believe we are on the path to meeting targets and providing analysis of possible future obstacles or issues.

5.4 Policy interaction and spatial scale

It is necessary to discuss how the CCC relates to different policy instruments and also spatial levels - be it a higher level e.g. EU and international climate change policy, or how it functions with UK-wide institutions, devolved administrations and local governments.

The decision making process of the CCC and the carbon budgets are heavily influenced by international and EU policy. The UK has commitments under the Kyoto Protocol and as such the carbon budgets must reflect this and be easily compatible with UN methodologies. Emissions in the UK are also heavily dependent upon EU policy, in particular the EU ETS, a policy instrument which covers roughly 50% of UK emissions. The policy interaction between the CCC's domestic carbon budgets and the EU ETS is a rather interesting area. As mentioned before, the EU ETS is an external factor than can influence the ability of government to meet the carbon budgets set by the CCC. How tight the EU ETS cap is and the ensuing carbon price will influence UK emissions and so it makes sense to set UK targets predicated upon EU targets. In acknowledgement of this the CCC initially created two possible carbon budgets: an "interim" budget and a tougher "intended" budget. Which one is adopted is dependent upon what cap is set in the EU ETS, which in turn is dependent upon whether there is a credible international agreement involving major polluters out-with the EU. If there is such an international agreement, then the EU will adopt a 30% reduction (as opposed to 20% if no agreement) by 2020 and this will then tighten the EU ETS allocation between 2012-2010 and increase the price of allowances.[60] This is due to worries about competitiveness effects and to hopefully incentivise others to follow the EU's example. Therefore the UK government will decide what budget to follow, intended or interim, dependent upon the EU's action and price estimations. Regardless, it is certain that the EU ETS will influence the domestic budget as around half of all the emissions in the UK are covered by the EU ETS. For those sectors not covered by the EU ETS e.g. transport, perhaps a CCC-controlled carbon tax or a separate trading scheme would be beneficial as a domestic policy instrument. Boemare *et al* (2003) highlight the issues between having national and European policies on emissions trading.

The accuracy of the CCC budget recommendations are actually heavily dependent upon the success of the EU ETS i.e. having a credible carbon price and a certain amount of trading is incorporated into the CCC models when deciding on the budgets. Much of the CCC analysis and modelling uses an estimated average carbon price of £40 per tonne of carbon in 2020 under a 30% EU target and central fossil fuel price assumptions, with sensitivity analysis where appropriate. Therefore the extent to which this price prevails in practice will affect the UK's ability to achieve carbon budgets and so the success of the EU ETS is critical to the success of the CCC. Recent price trends have shown some volatility and lower than expected prices.[61]

There have been issues with the EU ETS in terms of keeping a stable price, which has fluctuated in part due to over-allocation of grandfathered emissions allowances and the inability to bank and borrow allowances between periods. The EU ETS could be strengthened post-2012 with the introduction of more auctioning of allowances,

[60] The 4th carbon budget suggested tightening the "non-traded" sector budget to achieve a 37% reduction by 2020

[61] The EUA price fluctuated mostly around 12-16 Euros per tonne of carbon in 2009

which has been advocated by many academics (Grubb and Neuhoff, 2006) to minimise rent-seeking by covered companies, who currently benefit by making windfall profits from the grandfathering allocation of allowances. Auctioning would also allow for revenue recycling by governments and could therefore generate a double dividend.

The introduction of a price floor and ceiling would also substantially limit the possibilities of large variations in the carbon price and therefore increase certainty for investment in low carbon technologies (Helm 2007b, 2009, 2010). A price-floor could be introduced by an agreed carbon tax making it a hybrid scheme where a low tax would prevent the price falling below a certain level. A ceiling could be imposed by establishing buy-out clauses. This could be done centrally at EU level to harmonise the tax floor across the EU.

The EU ETS is currently linked to the Kyoto flexible mechanisms through the Linking Directive[62]. This allows for lower abatement costs as well as technology transfer to developing nations. The CCC has stated that there should be absolutely no limit on the amount of EU ETS allowances purchased, as total emissions within the EU should remain the same. However, they advise that credits from Kyoto flexible mechanisms, such as the CDM, should be limited in meeting the carbon budgets, even though these projects would theoretically achieve abatement at lowest cost. This advice is due to concerns that no significant reductions would be made if the use of Kyoto credits are not limited as many groups are sceptical about the true benefits of such project credits. This scepticism is due to the difficulty in proving the ‘additionality’ of such projects against a hypothetical baseline scenario. If these CDM projects are not credible then this undermines the whole process. Therefore domestic reductions which can be accurately measured are preferred. However, the Linking Directive already allows the use of Kyoto credits in the EU ETS although their use can be limited by governments in their National Allocation Plan. Price credibility and stability could also be enhanced in the future by linking the EU ETS with other trading schemes worldwide once those in the USA, Australia and Japan

[62] Directive 2004/101/EC

are functioning. Although it would go some way to achieving a worldwide carbon price though this would not be unproblematic as a merging of prices, assuming price differentials, would be socially but not pareto optimal, as those buying in the ‘low price’ scheme will now face higher prices and those selling in the ‘high price’ scheme will now receive a lower selling price. The success of linking will be dependent upon the characteristics of both schemes, and the more similar they are, the easier linking will be. Do they have the same emissions reduction targets? Are different GHGs covered by the schemes? How are the schemes’ units of currency exchanged?

More generally, the time-inconsistency problem is caused by the fact that policy-makers change after a certain number of years, or to put it another way, time-inconsistency is a by-product of the electoral process. Ulph and Ulph (2009) acknowledge this and put forward an argument that other policies, such as R&D subsidies, must be employed in order to induce investment in clean technologies, in cases where governments cannot commit. They argue that where a future government may attach a different weight to the environment, the current government has an increased incentive to have the necessary investment take place but the private sector has less incentive to invest. Therefore additional policy instruments may be required to achieve the level of investment needed. However one issue with this model is that it ignores the requirement of substantial funding from the current government and is it fair to incur heavy costs now through subsidies. This governance issue may differ at EU level as policies tend to change a lot less quickly. The EU as an organisation is long-lived and may be better placed to deal with such time-inconsistency issues but it is more susceptible to bureaucracy in achieving its goals. Helm (2009) agrees that the EU level is more appropriate for tackling climate change than many national schemes, given the global nature of the problem, but he warns against the climate change ‘pork-barrel’ becoming the new Common Agricultural Policy where vested interests produce inefficient polices that exist long past their usefulness because rents are there to be captured.

Domestically in the UK there has also been use of energy and carbon markets as policy levers to achieve emissions reductions. The Climate Change Levy is fundamentally a tax on energy intensive sectors. Large discounts up to 80% are available however for sectors that can form Climate Change Agreements (CCAs). Also from 2010 the introduction of the Carbon Reduction Commitment (CRC) will provide a carbon trading scheme for large businesses who consume more than 5000KW per annum e.g. Tesco, Universities. Revenues from the CRC auctioning process were originally to be recycled back to participants providing they meet efficiency targets but this has been modified by the Government as a method of increasing fiscal revenue. This has unsurprisingly upset many of the participants covered by the CRC.

Renewable Obligation Certificates (ROCs) were introduced as a means of financially supporting renewable electricity generation in the UK.[63] The ROC scheme in the UK has been often criticised, initially for not differentiating among renewable sources which meant a dash-for-wind, as it was the most cost-competitive renewable covered by the scheme. This has recently been reformed into a "banded" ROC scheme. Also, the slow planning process is widely regarded as having hindered renewable development. It is not clear if the purpose of the ROC scheme is to reduce emissions or promote a new growth sector. The UK government has no clear energy policy goal to use renewables as a tool for economic growth; however the Scottish government has made this priority explicit. Also the ROC support scheme applies to electricity production which is already covered by the EU ETS and therefore raises important questions of policy interaction. The EU does have a renewable energy target of 20% increase by 2020 however there is no EU-wide renewable certificate scheme and so renewable policies differ across the EU, with many other countries using feed-in tariffs, a direct subsidy rather than a trading scheme, to good effect.[64] There are plans by the new Conservative/Lib Dem coalition Government to introduce a feed-in tariff in tandem with ROCs and also to possibly introduce a carbon tax.

[63] This requires electricity suppliers to provide a certain amount of renewable power, or face a penalty. This should increase low-carbon electricity production and thus displace emissions from dirtier sources, whether that is the end goal or not. For an overview see (Morthorst, 2000)

[64] This target covers all energy sources including electricity, heat and transport

There is significant opportunity to introduce these reforms along with Ofgem's review into energy supply. A feed-in tariff would give more certainty of income to investors in renewables and a carbon tax could act as a price floor for the EU ETS and therefore provide more price certainty.

How these policies interact is of critical importance to energy policy and the success of reducing emissions. There is a tension between the emissions trading scheme on the one hand and domestic targets or renewable goals, on the other. In theory a trading scheme should achieve abatement at lowest cost and having additional policies would add no efficiency gains (Sorrell and Sijm, 2003). There needs to be at least as many policy instruments as policy goals. However, even using a single policy instrument in order to achieve each government policy goal may prove to be problematic due to the interlinking and potentially conflicting nature of these goals. In practice it is not clear that the UK government are even using separate instruments for each goal of energy policy and clear rules regarding the interaction of these objectives have never been outlined.

The CCC believes that carbon markets cannot be relied upon completely to achieve the carbon budgets:

"The Committee recognises the benefits of carbon markets, which can help achieve emissions reductions at least cost and drive emissions reductions in developing countries. But we believe that it is essential for rich developed countries to achieve significant domestic reductions to drive the development of required low-carbon technologies and to be on the path to meeting the deep domestic emissions cuts that will be required in the longer term"[65]

This statement seems slightly odd given the clear distinction and tension between the first and second sentences. What they seem to be advising is enforced innovation in developed nations, perhaps through renewable policy targets, but goes no way towards limiting their high-energy imports. Sorrell and Sijm (2003) propose that

[65] CCC (2008b), foreword p9

although additional policy instruments bring no efficiency gains, they can achieve other objectives such as stimulating investment in R&D where inducing initial investment is difficult because of moral hazard and imperfect information. This is similar reasoning as Ulph and Ulph (2009) in justifying R&D in renewable technologies. There is a role for markets but in the long run developed nations will have to change infrastructure substantially to achieve necessary emissions reductions, and to do this there needs to be immediate investment in new technologies. Surely these domestic reductions would be better achieved with an appropriate domestic policy lever for the CCC, rather than purely setting an aspirational future target. Helm (2007b) hopes that delegation of powers may be possible in the future, after an energy agency has been established for a long enough time for its reputation to be sustained through the government achieving its carbon budgets. This allows for the possibility that the CCC functions may change over time and even eventually become more comparable to the MPC.

There have so far been missed opportunities in terms of transforming and simplifying UK energy policy by incorporating other institutions' functions into the CCC. The CCC provides advice to government, while the Carbon Trust provides help for companies and organisations as well as funding low carbon technologies. The Energy Saving Trust has an even wider ranging remit, giving advice and information to anyone wishing to save energy in various ways, mostly households and small businesses. Security of supply is mostly handled by Ofgem. This overcomplicated arena is a flaw of the UK government energy policy as a whole. Helm (2007a, b) called for an energy agency which would be all encompassing. Such streamlining would allow cost reductions through economies of scale and possibly the reduction of lobbying by different energy-related institutions. Although the CCC cannot comment directly upon how government should decide policy, it should be able to comment upon possible policy instruments as methods for reducing emissions in specific areas. It should also be able to discuss policy interaction, an area which is often neglected by analysing what the effects of employing many policy levers at the same time may actually achieve.

Energy is a reserved matter for the UK government; however this constitutional issue has not stopped Scotland pursuing its own energy policies specifically on environment, security of supply, price and growth (Allan *et al*, 2008). The Climate Change Act (Scotland) 2009 has created legislation guiding Scotland towards lower GHG emissions. It is completely independent from the UK act and it has many similarities but a few important differences. The Scottish government asked the CCC to advise Scotland on: the highest achievable interim target for 2020, the annual targets from 2010-2020, a cumulative emissions budget, how to include aviation and shipping within budgets; and limits of credits to meet Scottish targets. Their report was released in February 2010 and highlights the main differences between the Scottish and UK frameworks and how Scotland can attempt to meet its ambitious 42% reduction by 2020 (CCC, 2010). It is important to note however, that CCC is responsible towards the Scottish Government but not the Scottish Parliament. This is in contrast to the UK level where the CCC advises Government but also must report to Parliament.

The CCC advice suggests this target is possible but setting separate targets for the traded and non-traded sectors in Scotland and making the non-traded target invariant to whether a global deal is achieved. This non-traded sector reduction would have to be around 47% to meet the overall economy target of 42% reduction in GHG emissions. The main differences between Scottish and UK policies are interesting and worth discussing. A ‘no nuclear’ policy is currently held by the government in Scotland, based mostly on political reasons, and this severely limits options available for low-cost, low-carbon technologies available to meet the demanding emissions reduction targets. Scotland also has very demanding renewable electricity target of 50% by 2020. The strict planning permission system may make it difficult for this to be achieved in time without intervention from the government. The Scottish framework also explicitly includes aviation and shipping, which are not yet included at UK level. The inclusion of aviation and shipping, whose emissions growth is outwith Scottish control, will require more stringent reductions in other sectors. Another difference is that the Scottish act provides for annual reduction targets instead of the 5 year UK carbon budgets. This reduces the flexibility of meeting targets, as does the lack of borrowing allowed between Scottish budgets. All of these differences suggest that meeting the Scottish targets is achievable but will be a substantial challenge, especially if there is no international agreement meaning the EU target remains at 20%.[66]

6. CONCLUSION

There is no simple way to reduce worldwide GHG emissions in order to stabilise global temperatures and minimise the effects of climate change. An international climate change agreement is necessary in the long term but this has proved to be politically difficult and laborious to achieve. Therefore domestic and regional initiatives have become essential in tackling climate change. These may take the form of emissions taxes, trading schemes and government regulation. Emissions levels may also change indirectly due to the other government energy policy goals, such as security of supply or promoting a renewables industry. One interesting institutional approach to tackling climate change is the creation of an independent body which may be tasked with a combination of: validating information on climate change, giving scientific and economic advice, monitoring government emissions' reduction targets, and having the responsibility for achieving such targets (and policy instruments with which to achieve them).

The Committee on Climate Change is a unique institution that has been created to make the UK a leader on the climate change issue. Any country willing to take the initiative domestically on climate change should be commended politically for trying to show leadership. However, such a move may prove risky in terms of reduced growth and competitiveness, if it fails to induce others to follow. There are a number of possible reasons for the creation of such a body. In the UK the most compelling motivation depends on an analogy with the use of an independent central banker to solve the time inconsistency problem, which is familiar from monetary policy. However, in practice, the institutions created to tackle these time inconsistency problems in monetary policy and carbon policy, the MPC and the CCC respectively,

[66] See Appendix B for an overview of Scottish climate change policy

differ significantly. These differences are apparent in terms of the problem they are trying to solve and also how they operate.

Firstly, the time scales involved in carbon and monetary policy differ substantially. Weightings of future generations appear to be an important consideration in analysis for carbon policy and investments in renewables have a long life cycle, so that the discount rates used in each body's analysis tend to differ slightly.

Secondly, although both bodies require judgement from committee members, there are considerable differences in the technical decisions they have to make. In particular, climate change appears to be more uncertain and far more complex to comprehend, various equity considerations have to be taken into consideration (such as an appropriate UK share of global emissions reduction efforts) and there is not the same clear link between policy instrument and goal (carbon targets and temperature) as with monetary policy (interest rate and inflation).

Thirdly, there are important institutional differences between the areas of climate change and monetary policy. The MPC is the main monetary policy institution and although it must function in tandem other government economic goals, its remit is more concise than that of the CCC. The CCC has to operate with other government energy policy goals where there appears to be considerable overlap and trade-off between these goals. Therefore the CCC remit is wide-ranging as it takes extra considerations into account. It also exists within the crowded institutional landscape of energy policy alongside other environmental and energy related bodies such as the Carbon Trust and Ofgem, this substantial overlap does not occur within monetary policy.

Perhaps due to these previous differences an important fourth difference arises. Unlike the MPC, the CCC has no direct policy instrument; there is therefore a question over its likely effectiveness in solving a time inconsistency problem and creating a credible carbon policy. In practice the CCC is the 'inverse' of the MPC in the sense that it *advises on setting a target* rather than being *required to achieve a* *target*, whereas the MPC is charged with achieving the target set by the government through the use of the policy instrument delegated to it (the setting of interest rates).

It is clear that the CCC is emphatically not "the MPC of carbon policy". Rather it should be viewed as a "Rolling Stern plus" body that incorporates both an advisory role, similar to Stern (2006), reflected in its recommendations of 5-year carbon budgets, *plus* an additional monitoring function to detail whether targets are being, or are likely to be, met. However, unlike the work of Stern, the workings of the CCC are heavily enshrined in legislation. The CCC cannot simply be viewed as just another government advisory body or NDPB; it is heavily enshrined in legislation and is a crucial part of the UK government's climate change policy framework. Instead it must be seen as a guiding body and source of advice, which also publicly monitors government progress towards emission reduction goals, and whose independence and credibility is essential to the success of the UK effort to mitigate and adapt to climate change. It is this *plus*, of an additional independent monitoring role, that makes the CCC a unique institution within any national carbon policy and its independence is fundamental to its make success by holding political decision-making to account. Hopefully the CCC can develop and sustain a reputation for impartiality, and thereby establish credibility in climate change policy, over a time frame necessary to achieve the required emission reductions and changes in our use of carbon and other GHGs.

In its current form the CCC clearly has the potential to strongly influence and shape UK carbon policy over the coming decades and to help create a low-carbon economy. However, it may be that further improvements can be made to the CCC's role and functions. Firstly, there is a role for information provision to the general public and private sector. A credible source of information is needed to minimise the probability of events, such as the "Climategate" incident, which can seriously dent confidence in the science and economics of climate change. Information disseminated in a simple and transparent manner by a trusted independent body may help ease these issues. This is a function that could be performed by the CCC or another independent energy institution. If the CCC were to undertake this task it would allow for some simplification of the complicated carbon policy institutional setup. However, this role is more appropriate for a purely monitoring body. The CCC's strong alignment to the climate change agenda and its advisory role may compromise the impartiality of information of this nature.

Secondly, the CCC could fulfil its general responsibilities more effectively if it adopts a wider approach that includes consumption-based accounting methods for emissions, in tandem with the current production approach. This which would give a broader and useful supplementary indication of what level of emissions the UK is ultimately responsible for worldwide. Many energy intensive products are imported from countries where energy costs are cheaper and production-based accounting methods do not give a full picture of the extent to which public and private consumption by UK citizens is contributing to climate change. In some instances these production sectors may have moved from the UK. Therefore the CCC should take broader methods into account when advising on targets and advise on possible policies to achieve consumption reductions. One possibility that could be considered as a possible solution if climate change is actually to be tackled at a global level is a border carbon tax, although a tax may further harm competitiveness of some industries. However, macroeconomic impacts can be broadly neutralised by imposing a balanced-budget fiscal stance.

Therefore thirdly, if the CCC were given control of an appropriate policy, such as a balanced-budget carbon tax, they may be able to achieve the budgets and establish greater credibility, independently of other government policies. A national carbon tax may be appropriate for many reasons: inducing uncovered sectors of the EU ETS to lower their carbon emissions; raising revenues which can be recycled; and also achieving carbon price stability by imposing a price floor. It is likely that such a tax will be introduced, possibly at the EU level, but more likely at national levels.

Interactions between institutions and instruments must also be considered in depth and it would seem appropriate for the government, especially at a time of making spending cuts, to simplify the energy policy landscape. Remits of energy institutions are often overlap and can sometimes appear quite vague. These should be made more obvious and the exact purpose of instruments should be made clearer, giving an unambiguous indication as to which goal(s) they pertain to.

While I am are fully supportive of the adoption of emissions targets and of the need to monitor progress towards them, it is nevertheless important to keep the limitations of targets in mind. Targets are merely indicators of progress towards a particular goal, and from a policy perspective it is rarely sufficient simply to know if targets are being met or not: rather it is important to know why emissions are changing in a particular direction and by the amount observed. It is also important to understand, for example, the nature of the trade-off between environmental and economic goals, and the extent to which the adoption of low carbon technologies, for example, can ameliorate any trade-off. In short, there is a requirement for a modelling system that captures the transmission mechanisms from policy instruments to policy goals. No doubt the Department of Energy and Climate Change (DECC) and the CCC are already engaged in the development of such models (and, of course, there are a number of extant UK models that might be adapted for this purpose).

Such an energy-economy-environment modelling framework for the UK would facilitate an exploration of hypothetical policy packages, including the likely impact of a CCC-administered, balanced-budget carbon tax on specific sectors and on the economy as a whole. Distinguishing between covered and uncovered sectors of the EU ETS would allow analysis of interaction of a carbon tax, for example applied only to uncovered sectors, and the exogenous EU ETS carbon price. Ideally future extensions of such a model would also capture interaction of other key energy policy instruments (such as ROCs). A multi-regional variant would permit exploration of the spatial dimension that may prove critical given the nature of multi-level governance in the UK, especially since Scotland has its own climate change framework and emissions reduction targets.

Chapter 3

A UK Input-Output analysis: Emissions attribution and the EU ETS

1. INTRODUCTION

Domestically the UK has committed in the Climate Change Act (2008) to an 80% reduction in greenhouse gas (GHG) emissions by 2050, compared to 1990 levels. The UK has also ratified the Kyoto Protocol and has therefore committed to meeting an emissions reduction target of 12.5%, compared to 1990 levels, by the end of 2012. However, Kyoto has a rule which allows for nations within the EU to meet an overall EU target of an 8% reduction. The EU created a policy instrument to allow this target to be met in the form of a permit trading system (the EU Emissions Trading System). The EU ETS is a 'cap and trade' system where a limit is put on total emissions based on Kyoto commitments and the scheme allows CO_2 to be bought and sold between operators in certain emitting sectors.[67] The purpose of the scheme is to allow emissions reductions to take place where they can be met at least-cost within the EU.

The UK Government has committed to tackling climate change at a national level through the introduction of the Climate Change Act 2008. This act requires the UK to achieve an 80% reduction in GHG emissions, compared to 1990 levels, by 2050. To ensure the UK is on a path towards meeting the 2050 target, an interim target for 2020 has also been set. This target is dependent upon whether an international agreement is in place. If such an agreement is achieved then the UK interim target is for a 42% reduction compared to 1990 levels. This reflects the fact that the EU will move to a 30% target in this instance and therefore the cap of the EU ETS will tighten. If no international agreement is reached, the EU target for 2020 will remain at 20% and the UK will set only a 34% interim target. The Climate Change Act also requires 5 year carbon budgets to be set and consequently met until 2050, the first

[67] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003

three of which have already been set. The UK can be split into industries covered by the EU ETS (the traded sector) and those industries to which the EU ETS is not applicable (the non-traded sector). Emissions for the traded sector in the carbon budgets will be accounted for using the UK's average annual EU ETS cap.

Although there are considerable GHG emissions from sectors in in both the traded and non-traded sectors it is necessary to identify between these in the modelling of the carbon tax in order to identify which sectors are already covered by a carbon price. Multi-sectoral economic modelling tools are used to analyse the effects of environmental policies. This chapter identifies which activities are included as part of the EU ETS from those which are not in order to allow modelling of policy changes on these sectors. I undertake this by matching the EU ETS sectors to the economic accounts, in the form of an input-output table for the UK. An input-output table is used because it will form the database of the computable general equilibrium model that is most appropriate to simulate the effects of a policy shock in Chapter 5.

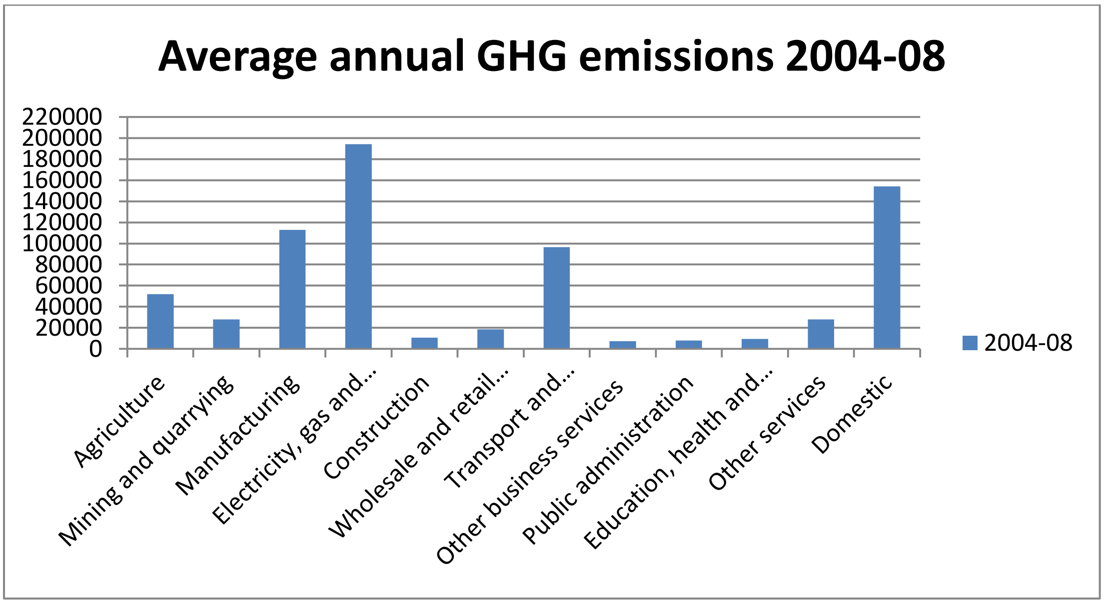
In Section 2 I give details on the UK GHG emissions by sector and discuss what sectors appear to be the most emissions-intensive. In Section 3 I give an overview of the EU Emissions Trading Scheme and discuss its coverage. Section 4 gives an overview of Input-Output (IO) accounts and modelling in general. Then I discuss how I identified those sectors covered by the EU ETS in the UK IO database in Section 5. In Section 6 I conduct an IO multiplier analysis and describe the results. Section 7 gives the conclusions of this work.

2. DESCRIPTION OF UK SECTORAL EMISSIONS

Any UK policy targeted towards emissions reduction must concentrate on the sectors which are the most polluting and need to be addressed through appropriate policy measures. The following description is of emissions statistics for the UK economy using the Environmental Accounts (ONS, 2010a) from 2004 to 2008. The GHGs described are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur dioxide. These gases are the main GHGs covered by the Kyoto Protocol and all of them are counted in tonnes of carbon dioxide equivalent. I concentrate mostly on the overall level of GHGs and also on carbon dioxide, methane and nitrous oxide. The time period from 2004 until 2008 is described because it represents the economy in its most recent state and also because publications of statistics for more recent years are constantly being updated. Using an average over these five years allows for the possibility of outlying years and takes into account recent trends in emissions i.e. whether increasing or declining.

Figure 3.1 shows that GHG emissions in the UK appear to come from five main areas of the economy. The "Electricity, Gas and Water Supply" sector is the largest GHG emitting sector of the UK economy as between 2004 to 2008 it accounted, on average, for 27% of the UK's total GHG emissions. The Environmental Accounts split this sector out further into electricity generating types. In particular 16.5% of total GHG emissions between 2004 and 2008 have come from coal power stations used to produce electricity and 8.1% of emissions have been from gas power stations for the same purpose, whereas nuclear power is responsible for less than 0.01% of the UK's emissions.

Figure 3.1: Average annual UK Greenhouse gas emissions from 2004 to 2008 by source in thousand tonnes of GHG



Source: ONS (2010a)

The second largest amount of emissions comes directly from the "Domestic" sector i.e. household consumption, which accounts for an average of around 21.43% of the UK's GHG emissions over that same five year period. It is important to note that this is not from a direct production sector of the economy but purely from the households' consumption of various goods and services. That is to say that although there are considerable emissions created in producing goods to be sold, there are also often direct emissions in the consumption of certain goods by individuals, such as pollution caused from fuel in family cars or from household waste. This sector is split further in the Environmental Accounts between travel and non-travel which account for about 9.3% and 12% of UK GHG emissions. This shows that it is not just producers of goods but also consumers that are directly responsible for contributing towards climate change.[68] Households can also be considered as being indirectly responsible for emissions from all of the production demand, so-called 'indirect consumption demand' (Gay and Proops, 1993), because intermediate demand is then purchased by one of the final demand sectors, the largest of which is the household sector.

The third largest producer of GHG emissions is the "Manufacturing" sector. This sector covers a whole range of industries that produce manufactured goods, including "Food and Drink", "Machinery", "Pulp, paper and paperboard" and "Motor Vehicles". None of these sectors are particularly large emitters by themselves, although there are some which are quite energy-intensive. However, combined, production of various goods in these manufacturing industries contributes to about 16% of GHG emissions. It should be noted that some of these manufactured goods will be exported and consumed (or used as inputs to production) in other countries. Currently UK emissions are accounted for on a production basis, which is to say that only emissions produced within the UK's borders are accounted for. However, the UK also imports many energy-intensive goods which means that the UK may be responsible for the consumption, whether as final goods or inputs to production, of goods and corresponding emissions produced in other nations. This raises questions

[68] There is also an argument that consumers should be responsible for emissions created in the production of goods and services because it is the consumer who purchases the final good. It is possible to account for emissions from a consumption perspective.

about whether the producer or consumer should be held responsible for emissions and also whether accounting for emissions in the UK should be based on a consumption basis as opposed to the current production basis.[69]

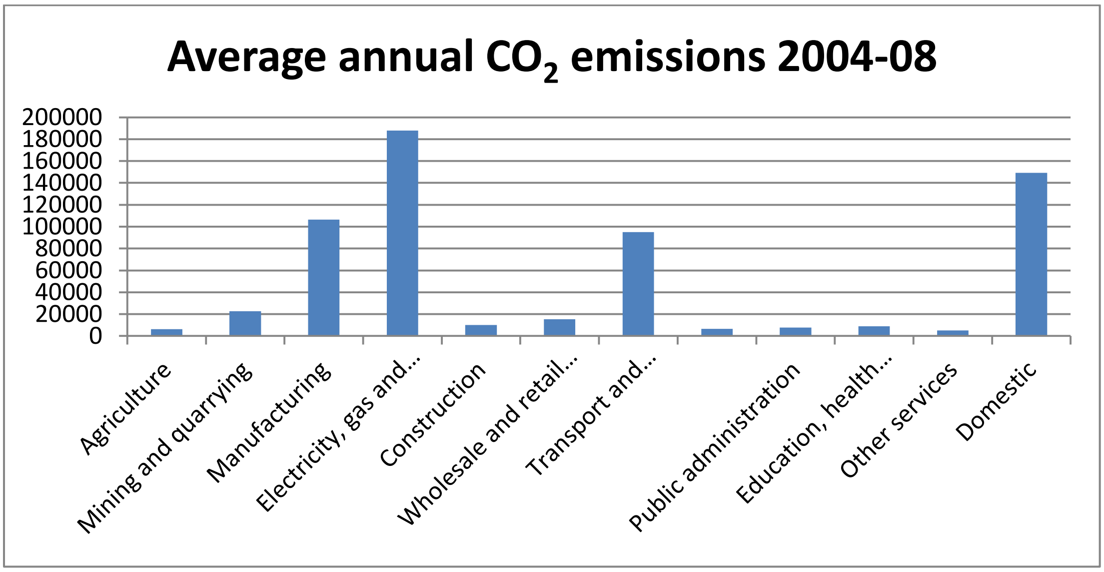
Fourthly, the "Transport" sector emits a substantial amount of GHGs at around 13.4% of all GHGs. The sector details all transport used for distribution of goods and services in the UK as well as the communication industry. It can be disaggregated into various types of transport, in particular, to show that Aviation is an emissions intensive sector of the economy accounting for almost 6% of total UK GHGs, while Water transport produces just over 3% and Freight transport by road emits 2.4% of total GHGs.

Finally, the "Agricultural" sector is a substantial emitter of GHGs into the atmosphere. In the UK it is responsible for around just over 7% of total GHG emissions. These emissions mostly come specifically from methane and nitrous oxide which account for around 36% and 51% of total agricultural GHG emissions respectively.

Overall, carbon dioxide accounts for 86% of total GHG emissions in the UK on average between 2004 and 2008. If we concentrate solely on carbon dioxide emissions then the figures and main emitting industries are similar to all GHGs with only a few differences, as is apparent from inspection of Figure 3.2. "Electricity", "Domestic", "Manufacturing" and "Transport" are still the four largest producing sectors of CO_2 emissions respectively contributing to over 86% of total emissions. In particular emissions from gas and coal technologies for the production of electricity contribute around 9% and 19% of total UK CO_2 emissions respectively. However, "Agriculture" is not particularly CO_2 intensive and accounts for only about 1% of the UK's total CO_2 produced.

[69] For an analysis of consumption and production accounting for emissions see Munksgaard and Pederson (2001) for the case of Denmark

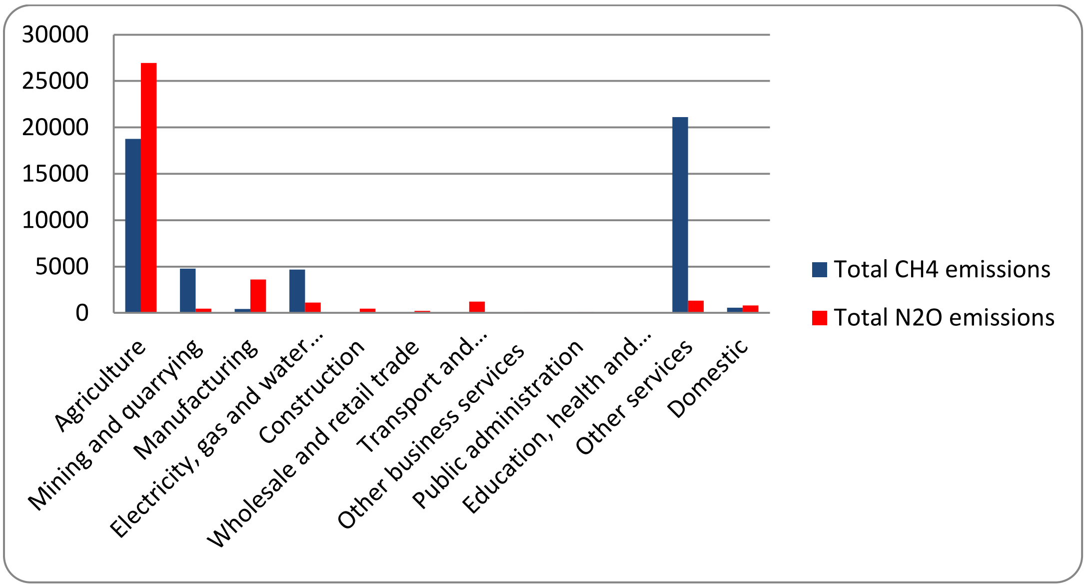
Figure 3.2: Average UK carbon dioxide emissions from 2004 to 2008 by source in thousand tonnes of CO_2



Source: ONS (2010a)

Methane and nitrous oxide emissions are shown in Figure 3.3. Methane is the second largest individual GHG in the UK and is responsible for 7% of total UK GHG emissions. Most methane emissions are attributable to “Solid waste”, “Agriculture” and “Gas distribution” sectors. Nitrous oxide is the third largest GHG, accounting for about 5% of total UK GHG emissions. Nitrous oxide emissions are almost exclusively in the “Agriculture” sector, 74%, but there are also some emissions from “Sewage”, “Fertilisers”, “Organic chemicals” and “Coal electricity production” sectors.

Figure 3.3: Methane (CH4) and nitrous oxide (N2O) emissions by source in thousand tonnes of CO_2 equivalent



Source: ONS (2010a)

3. PERMIT TRADING: THE EU ETS

In attempting to tackle climate change there are various options for governments to take action. They can enforce “command and control” mechanisms which would regulate emissions by using legislation to ensure that standards are imposed and sanctions are used where compliance with these standards is not achieved. This may be in the form of imposing efficiency standards for electrical appliances or for catalytic convertors in motor vehicles. Another option, generally preferred by economists, is to use market mechanisms which, if they work efficiently, should ensure that emissions reductions take place with minimum cost by making the marginal abatement costs of all participants equal across the board. This could be in the form of a tax or a permit trading scheme. I return to the idea of a carbon dioxide emissions tax later on but for now concentrate on a quantity instrument, in particular the world’s largest emissions trading scheme, the EU ETS, which the UK is a member of. It was created by the EU to enable it to meet its commitment under the

Kyoto Protocol. Phase 1 of the EU ETS ran from 2005-2007 and Phase 2 is running in parallel with Kyoto from 2008-2012.

There are several issues that need to be considered when implementing a permit trading scheme and these are considered in relation to the EU ETS. Firstly, defining the coverage and scope of the scheme is necessary. Therefore it must be clear what emissions are included in the scheme and who the participants in the scheme will be. Currently the EU ETS applies to carbon dioxide.[70] It is exclusively CO_2 emissions however, and not all GHGs, that are covered by the EU ETS and this distinction is very important since Kyoto commitments are in terms of GHGs. The EU ETS will be extended in its third phase, 2013 onwards, to include more gases[71]. Not all carbon dioxide emitted is part of the EU ETS but only CO_2 from certain sources in production. The sectors currently covered are defined by the activities listed in Annex I of the Directive and come under the broad headings: *energy*, *ferrous metals, minerals and pulp and paper*. All installations which come under these headings, and are thus covered by the EU ETS, require a permit to operate. There are around 10,500 installations covered by the scheme throughout the EU.[72]

It is important to understand the reasoning behind why certain sectors of the economy are covered by the EU ETS, which together are referred to as the "traded" sector, and others are not, collectively the "non-traded" sector. Obviously, the main reason many sectors are included is because they are the major heavily polluting industries in terms of CO_2 emissions in most European economies but also due to the difficulty involved in accounting and tracking emissions from other sectors. There are other sectors, such as transport and agriculture that are not covered by the EU ETS. This is mostly because of the difficulties encountered in attempting accurately to account for emissions in these sectors. Therefore the "traded" sector appears to

[70] Although nitrous oxide emissions from certain industrial processes are also covered as part of the scheme but these are relatively minimal and as such are generally not discussed in the thesis.
[71] These include nitrous oxide from acid production and perflurocarbons from aluminium production
[72] There are various exemptions from the EU ETS. Often smaller installations are not included because transaction and monitoring costs are deemed too high for them to take part without affecting competition.

comprise heavily polluting industries whose carbon dioxide emissions can be relatively easily measured and tracked allowing for relatively simple administration.

The EU ETS is a “cap and trade” scheme which means that an upper boundary on emissions must be set and permits are created up to this limit. This cap is set by a central policymaker, in this instance the EU, and thus determines the aggregate supply of permits. Aggregate demand is set by the installations in sectors that are covered by the scheme which were detailed above. These permits are then traded based upon whether have a surplus or not. Those installations which emit less than their allocation will become sellers and trade with buyers who will be the installations which emit more than their allowance. There is a sanction in place for those installations which do not have enough permits to cover their emissions. This will be significantly large to make the purchase of credit cheaper than the fine for non-compliance. In the EU ETS it is European Union Allowances (EUAs) which are traded and one EUA allows the holder to right to emit one tonne of CO_2.

One important decision for any permit trading scheme is how allocation of the allowances takes place. Although aggregate allocation is decided at EU level, actual allocation to participants is performed by each individual Member State and details of how their allowances are allocated to installations within their territory are detailed in each country’s National Allocation Plan (NAP) which must be approved by the European Commission. Allowances can either be given for free, a method known as Grandfathering, or they can be auctioned to those people who require them or even a mixture of the two. Although in theory the method of allocation should not affect the outcome (Coase, 1960), in practice the method of allocation can have significant impacts upon who are buyers and sellers, as well as the price traded, in the market. The EU ETS Directive required that at least 95% of the initial Phase 1 allocation had to be completely free of charge and this has been tightened to 90% free allocation in Phase 2. This has been one of the most contentious issues regarding the EU ETS where grandfathering in Phase 1 lead to significant “windfall profits” for electricity producers, where there is limited international competition, while passing opportunity costs on to consumers (Grubb and Neuhoff, 2006). There has been a move towards more auctioning of permits recently which has the benefit of generating revenues for the Government who can recycle them to finance environmental policies; to lower distortionary taxes; fund R&D, or to offset competitiveness effects. In 2008 in the UK there were 214 million allowances allocated for free and only 4 million allowances auctioned. This gives an indication of the disparity between the two. From 2013 the electricity generation sector will be wholly auctioned in the UK to correct the previous failures.

Banking and borrowing of credits are, in general, an important element of any trading scheme as they allow flexibility in meeting quotas. Depending on expectations of future abatement costs, firms in the scheme will choose to either bank credits, by putting in effort now and banking any excess until the future selling price is higher, or by borrowing now against future allocations if abatement is going to become cheaper in the future. The EU ETS did not initially allow banking between phases and this caused a price crash at the end of Phase 1. There is no borrowing allowed in the EU ETS.

In terms of the effects that the EU ETS has on individual firms that are covered by the scheme there are a number of considerations. There are several different transaction costs involved in the scheme. Firstly, there are terms of initial implementation costs in order to comply with the scheme. For most firms these occurred in 2005 when the first phase began although new entrants may have to incur costs in terms of time and staff, consultancy costs and capital equipment to calculate emissions. Secondly, the monitoring, reporting and verification (MRV) of emissions involves costs which firms must undertake to ensure compliance with the scheme. These will be annual costs and will be dependent upon factors such as the volume of emissions. Thirdly, there are trading costs involved in selling and purchasing emissions certificates. Many firms have previously not had any experience in this area and so either training or outsourcing is required. There is an incentive for firms to abate emissions in order to comply with their allocation or even sell excess certificates. Therefore abatement can be achieved through retrofitting, changing the production process, investment in new efficient technology, or fuel switching, all of which can be costly to implement.

Heindl and Lutz (2012) provide case studies of different EU ETS firms in Germany. They found that while the management of monitoring, reporting and verification was complied with internally, the actual emissions trading element was often outsourced and these intermediaries were important. They also highlight that existing volumes of emissions and production patterns are important for firm activities in the EU ETS. Larger emitters are much more engaged in trading, efficiency and innovation than smaller emitters due to economies of scale and high transaction costs. Around 69% of transaction costs in Germany came from MRV compliance while about 20% was trading costs and 11% from information on abatement technologies. A survey of these types of transaction costs incurred by EU ETS firms in Ireland was undertaken by Jaraite et al (2010) and find that such costs per tonne of CO_2 are higher for smaller firms, €2.02 per tonne, compared to larger firms, €0.05 per tonne which shows that economies of scale certainly exist. It would be helpful to undertake a similar survey of EU ETS firms in the UK in order to establish.

One potential concern is that in incurring these costs, the competitiveness of firms will be affected causing reallocation of their business outside of the EU. For some industries this is not an issue because of inelastic demand e.g. electricity, specific industry characteristics e.g. market structure, or a lack of international competition. However, other energy-intensive industries such as steel and cement could be susceptible to such competition. This would have the effect of lowering domestic emissions and economic output. If consumption of goods produced by such industries remains then while there is a reduction in production emissions there will in effect be carbon leakage where emissions-intensive goods are simply imported. The movement of such firms would require a tightening of the EU emissions allocation in the future. So far it has been too soon to tell if the EU ETS has affected competitiveness, especially given the over allocation of permits in early phases.

The EU ETS accounted for 49.8% of total emissions in the UK in 2008, the first year of phase II, and 48.2% of UK CO_2 emissions in 2009. The Kyoto Protocol requires reductions of other GHGs, such as methane, and if we take these into account then the EU ETS covered around 42.5% of the UK's total GHG emissions in 2008 and 40.3% in 2009 (DECC 2009, 2010c). The EU ETS is therefore a major policy tool in the UK achieving its emissions reduction targets. Given this coverage it is necessary to separate the industries in the UK into those that are and are not covered by the EU ETS.

4. INPUT-OUTPUT METHODOLOGY

An Input-Output (IO) table is used as the basis for the Social Accounting Matrix (SAM) which will form the database for the CGE model I intend to use to simulate a carbon tax in Chapter 5. I use an IO table of the UK economy for 2004 and identify which sectors of the economy are "traded" and "non-traded" sectors of the EU ETS. I want to identify which sectors I should include when aggregating the CGE in terms of those important to the economy and environment. It is possible to employ a number of assumptions to convert the IO database into a multi-sectoral macroeconomic model. This IO analysis is economy-wide and can track all changes through industries to final demand. It is also possible to incorporate environmental aspects by attaching emissions to output. IO therefore seems an appropriate multi-sectoral model to utilize for environmental purposes in deciding which sectors are important for the UK. This analysis distinguishes what domestic sectors are most important to the UK economy in terms of output and in terms of reducing emissions, which can then inform policy action. It will also allow us to say whether the EU ETS is targeting the correct emissions-intensive sectors in the UK.

4.1 Input Output Accounts

An Input-Output table is a collection of economic accounts for a specific place and time. These accounts will generally be sector purchases and sales data of a region or country for a specific year and many of these jurisdictions will publish official IO tables on a regular basis which can be used simply as accounts or for possible policy analysis. The IO system of accounts is based on the concept of double-entry book-keeping; each sale has a buyer and vice-versa, and therefore can be viewed as a snapshot of an economy which reconciles the income, output and expenditure measurements of Gross Domestic Product (GDP).

All of the economic transactions in the IO table are disaggregated into various sectors (or industries). The IO table itself details all of the inter-industry transactions within an economy and reflects the fact that all output of a sector requires inputs, whether in the form of materials, other goods, labour and capital. Each row of the matrix shows sales (inputs) and each column gives the purchases (outputs). The figures are usually measured in monetary values in a standard IO table (although quantity IO tables have been created), for example, the value in Pounds Sterling that the paper industry sold to the Finance sector in a given year. It is important to note that there may be issues with using monetary values rather than simply noting the quantity of goods sold from one sector to another. For instance, it may be the case that a particularly high price in a specific year may overestimate the significance of that selling sector. The IO table itself is split into four distinct quadrants of intermediate demand (or processing sector); final demand; value added, and value added for final demand.[73]

In the intermediate demand section all sectors of the economy produce an output which is then either purchased by another sector of the economy (or even itself) or is sold on to final demands within the economy. We therefore know where all inputs come from and where all outputs go to. For example, it will detail what the “Food and Drink” sector has purchased from “Agriculture” in that given year in monetary terms. It is important to note that the ‘Food and drink’ sector’s demand for inputs from ‘Agriculture’ will be dependent upon the amount of goods produced by the food and drink sector.

[73] For a detailed textbook analysis of IO see Miller and Blair (2009)

The number of economic sectors in the intermediate demand table can be aggregated at various levels of detail depending on the data available. There may be simply one sector for ‘Food and drink’ or this may be disaggregated into dairy, sugar and beverages for example. The decision on the appropriate level of sectoral aggregation will differ depending on the reasons for construction of the database as well as the available data. A high level of aggregation in the table may be desired where there are many small, similar sectors which individually do not contribute significantly to the economy but taken together can be important in production. This may also be appropriate in multi-region models where there is limited data in one region. Aggregation also allows for a simpler interpretation of the economy and reading of results. This may also be appropriate where the concern is only with a few sectors of the economy and so the less important ones can be aggregated together. However, by undertaking aggregation you run the risk of introducing bias into the modelling outcomes. In practice IO studies vary widely in terms of their degree of aggregation.

The final demand columns detail the purchases of final goods and services by households, government purchases, capital and investment and net exports, all of which are treated as exogenous to the producing sectors. Therefore, unlike the intermediate demand sectors, the demands for these final demand sectors are not related to the amount being produced. For example, export demand will be related to economic conditions abroad. These final demands are the main components of GDP and so the sum of these final demands makes up GDP. Again these columns can be broken down into more detail if the data are collected in such a way. For instance, you may be able to distinguish between consumers of different income levels or possibly identify various aspects of government purchases or possibly detail the source of demand for the region’s exports.

The rows of value added give the other factors of production not purchased from other sectors such as capital and labour used to make products. That is to say those companies have to decide whether to make or buy materials. Compensation for employees e.g. wages paid for the labour inputs of households, are accounted for here, as are taxes paid for services that the government provide such as police and national defence. It is also the case that some inputs into sectors will not be produced in the area for which the table is constructed and therefore imports for each sector must also be accounted for in value added. This gives a good idea of what sectors are important for the region if there was an increase in demand and which sectors depend mostly on inputs from abroad. There is also value added for final demand which details what consumers, investors, government and exports pay for in terms of value added such as wages and taxes.

4.2 Input Output Model

The IO model is a demand-driven model originally developed by Leontief (1970).[74] The level of detail in the IO accounts allows for analysis of how exogenous changes or shocks in final demand can affect output for all sectors of the economy and allows us to view the entire economic system and identify what sectors are affected most by such shocks. This is why IO modelling is a tool often used by policymakers. However, there are certain assumptions necessary in input-output analysis. Firstly, that the supply-side is passive. This assumes that there are no supply constraints on the economy or individual sectors so that output can expand easily to meet any increases in demand, whether this requires capital, labour or raw materials i.e. the supply of all inputs are perfectly elastic. Secondly, there is an assumption of Leontief technology so that the ratio of inputs into production is fixed, for example, a doubling of output would require a doubling of all inputs. That is to say there is the assumption of constant returns to scale. If output is to be doubled then all inputs must be doubled and there is no substitutability. These assumptions give the equation:

$$x_{ij} = a_{ij}Xj \tag{3.1}$$

Where x_{ij} is the sales from sector i to sector j, Xj is gross output of industry j and dividing the former by the latter gives a_{ij}, which are the technical coefficients which specify how inputs are related to output. These technical coefficients can be defined

[74] Although conventional IO models are demand-driven there are also supply-driven IO models used

for all intermediate demand sectors of the IO table. It is the case that output in each sector of the economy is the sum of all intermediate demands plus final demand. Applying the technical coefficients to this relationship allows for the following set of linear equations:

(3.2)
$$X_1 = a_{11}X_1 + a_{12}X_2 + \ldots + a_{1n} X_n + Y_1$$
$$X_2 = a_{21} X_1 + a_{22} X_2 + \ldots + a_{2n} X_n + Y_2$$
$$X_n = a_{n1} X_1 + a_{n2} X_2 + \ldots + a_{nn} X_n + Y_n$$

Where X_i is the output of sector i, Y_i is the final demand of sector i and a_{ij} are the coefficients calculated from constant returns to scale and represents the amount of sector i's output that is required to produce a unit of sector j's output. In matrix notation this system can be written as:

(3.3)
$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{Y}$$

Where **x** is gross output vector, **Y** is the matrix of sales to final demand and **A** is the inter-industry input-output matrix of technical coefficients. The linear equations can be rearranged to give:

(3.4)
$$(1 - a_{11})X_1 - a_{12}X_2 - \ldots - a_{1n} X_n = Y_1$$
$$- a_{21} X_1 + (1 - a_{22})X_2 - \ldots - a_{2n} X_n = Y_2$$
$$- a_{n1} X_1 - a_{n2} X_2 - \ldots + (1 - a_{nn})X_n = Y_n$$

It is straightforward to use matrix algebra to rearrange and solve this system of equations to get the main equation used to solve for sectoral outputs:

(3.5)
$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}$$

$(\mathbf{I-A})^{-1}$ is referred to as the Leontief inverse matrix and this matrix an incredibly useful tool to use when analysing changes to final demand and so is the main equation for IO analysis. In practice this requires calculating the **A** matrix, then a **I-A** matrix, where **I** is an identity matrix with diagonals equal to one and all others equal to zero.

There are two main variants of the demand-driven IO model. Firstly, is the open system which treats all of final demand as exogenous which gives both the 'direct' and 'indirect' effects. The final demands are considered to be completely independent of economic activity, and as such cannot be influenced within the model. However, the intermediate demands are determined by activity and as so a change in final demands will therefore influence intermediate sectoral activity and may have a considerable feedback effect. When there is an exogenous increase to final demand for a specific industry, say exports of motor vehicle manufacturing, then the 'direct' effect is the change in the inputs to the motor vehicle sector needed to meet that new final demand, such as steel, rubber and labour. There is also an 'indirect' effect because the increase in manufacturing inputs requires a further increase in the inputs, for instance, the steel sector will have to purchase more inputs, and so on. Altogether these direct and indirect effects create an increase in overall output of the economy larger than the initial increase in demand.

Secondly, it is possible to treat households as endogenous and have what is termed a "closed" system. This essentially involves bringing consumption into the Intermediate demand part of the IO system and allows for the same analysis with Type 1 "direct" and "indirect" effects but also includes "induced" effects. This is a more accurate portrayal of the economy because in practice increases in household income, due to increased labour payments, will, more often than not, lead to households consuming more goods and services. This requires the household sector of final demand to be brought into the Intermediate demand system to make it endogenous to the model as if it is a producing sector and so the **A** matrix must expand so an n x n matrix will become $(n+1) \times (n+1)$ matrix. Here the last row will now show the purchases of labour services from households by the *n* sectors and the final column will show the household purchases from the *n* other sectors. The bottom right of the transactions table will show household purchases of labour.

It is possible to use the Leontief matrix to calculate output multipliers for each sector in order to measure the extent of increases in output attributable to a unit change in final demand. If you sum the figures for a column in the Leontief inverse matrix then you have the sectoral output multiplier for the industry in that column. This multiplier shows the overall effect on the economy of a unit change in that particular industry's final demands. For example, if the Agricultural gross output multiplier was 1.8 then that would imply that an increase in final demand for agriculture of £1 would result in an increase in gross output of £1.80. This is due to the increase in agriculture demand requiring an increase in the inputs to agriculture e.g. manufacturing of vehicles, machinery and labour. This in turn increases the inputs of these sectors and so on. This is where the passive supply-side assumption is important because it assumes excess capacity and so allows the supply of labour and capital to match any extra demand.

These multipliers can be calculated for the open system described above, called a Type 1 multiplier, where the direct and indirect effects are included in the multiplier. A multiplier can also be calculated for the case where household expenditure is endogenised by closing the system in the way explained above, called a Type 2 output multiplier. Generally the output multipliers are larger for Type 2 than Type 1 multipliers because with households endogenous to the system they now increase expenditure when their incomes are increased and therefore take so-called 'induced' effects into account. So with Type 2 multipliers a proportion of extra income is spent when more labour is employed as there is now a constant coefficient linking consumption to income in the same way that there are coefficients for each *n* producing sectors. In reality the amount of income spent by households depends on the spending pattern of consumers and the income levels of consumers and so will vary between different households. This is why the household sector is often disaggregated into income brackets.

It is also possible to calculate multipliers for physical amounts, such as employment, and as such IO analysis can be applied to energy and environmental concerns (Leontief, 1970; Gay and Proops 1993). This allows for the attribution of important environmental concerns within the economy such as carbon dioxide emissions.

$$\mathbf{X} = \boldsymbol{e}\,(\mathbf{I}\text{-}\mathbf{A})^{-1}\,\mathbf{Y} \tag{3.6}$$

The above equation is an extension of the one relating output to intermediate and final demands but where an additional e vector is introduced which are environmental pollutants. Where sectoral emissions data is available they can be linked to sectoral output to create a vector of emissions per unit of gross output for each sector, *e*. A similar analysis as above can then be carried out and multipliers calculated for tonnes of CO_2 released per £1million of output for each industry in intermediate demand. It is therefore also possible to attribute emissions to final demands which are the main drivers of production in the economy and identify both the direct and indirect emissions produced by that final demand. However, if you wish to include all emissions within a country you must also include direct emissions from final demand sectors such as households and government in the IO model.

5. DATABASE CONSTRUCTION

5.1 Economic and environmental accounts

The UK Government does not currently produce IO tables regularly; the last official one produced was for 1995.[75] Having timely data is particularly important for both output and environmental analysis because accounts may be misleading if used only for one specific year. That year may have had lower output and/or emissions than

[75] There was a table published in May 2011 but this was not available in time to be used for our work on this thesis, although updating the work using this table should be undertaken in future

others for some reason e.g. during a recession. The tables produced are based on the European System of National Accounts (ESA95) which in turn is based upon the United Nations System of National Accounts 1993 which has universal adoption. The production of ESA95 accounts is a legal requirement of EU members but there is no stipulation as to how frequently they must be produced.

Given that the UK has not produced an official table for over fifteen years I decided to use an unofficial but more recent table. The database used is an unofficial analytical IO matrix of UK industries for 2004.[76] The UKIO 2004 contains a symmetric matrix of 123 industrial sectors of the economy matching to SIC 2003 codes and is based upon the 1995 official UK IO table.

For the environmental side of the model the Environmental Accounts (ONS, 2010a) discussed earlier are used to calculate CO_2 and GHG coefficients for all sectors of the economy. The emissions data are broken down into 91 different industrial sectors as well as two consumer expenditure sectors (travel and non-travel). I concentrate solely on CO_2 in terms of GHGs as it is the largest contributor to climate change and is also the main EU ETS gas. However, I also use the overall GHG levels in order to identify any sectors which are important to climate change in terms of GHGs but not necessarily CO_2.

It was necessary to map the environmental accounts to the economic accounts. Information on GHG and CO_2 emissions is only available for 91 sectors of the UK economy in the Environmental Accounts. Therefore it was necessary to aggregate the 123 economic sectors to the 91 environmental sectors or less and match the emissions data to the corresponding IO sector. This was reasonably easy to match due to corresponding SIC 2003 codes for all entries. One exception is that the Environmental Accounts have the electricity sector disaggregated into production by fuel type and detail the emissions from each of these sources. These are coal, gas, nuclear, oil and other. However, the IO accounts aggregate all generation and other activities into a single row and column for Production and distribution of electricity.

[76] It was developed through Dr Karen Turner's ESRC Climate Change Leadership Fellow project (ESRC ref: RES-066-27-0029) at the Fraser of Allander Institute, University of Strathclyde in 2009.

I was therefore limited in terms of being able to distinguish electricity production types that are large carbon emitters e.g. coal, from those that are not large emitters e.g. nuclear, because electricity production is treated as one single economic sector. Also, the IO table was more disaggregated than the EA data for certain industries. For instance, there are twelve different food and drink sectors in the IO table such as “Dairy products”, “Sugar” and “Alcoholic beverages” yet there is only one EA entry giving emissions for all “Food and Drink” which covers emissions from all twelve of the IO sectors. This meant certain aggregation was required from 123 economic sectors and 91 environmental sectors in order to have a complete mapping of economic and environmental accounts of 67 sectors plus households.[77]

Once this was completed there was a UK 2004 IO table with emissions coefficients for that year.

5.2 Mapping EU ETS to the environment-economy accounts

In order to do further climate change policy analysis on the UK economy in relation to emissions, it was then necessary to attempt to identify which sectors from the 123 sector UK Input-Output model for 2004 appear to be directly covered by the EU Emissions Trading Scheme and this is not a straightforward task. [78] I attempt to distinguish those sectors in the table which are included in the “traded” sector of the EU ETS. Various sources of information on the EU ETS were used, in particular DECC (2009, 2010c) and ILEX Energy Consulting (2005).

[77] A complete mapping of the 123 economic accounts and environmental accounts are provided for in Appendix C.

[78] It should be noted that the most recent IO table is for 2004 and the EU ETS phase I did not come into operation until 2005. Therefore it is impossible to accurately match the two in this analysis.

Table 3.1: EU Emissions Trading System (EU ETS): UK 2008 data

Sector	Installations	Allocated 2008 MtCO2e	Verified Emissions 2008 MtCO2e	Total Surrendered 2008 MtCO2e	EUAs Surrendered 2008 MtCO2e	CERs Surrendered 2008 MtCO2e
Combustion	716	150.9	211.6	211.9	209.4	2.7
Mineral oil Refineries	14	18.6	17.5	17.5	17.5	0
Coke Ovens	1	0.1	0	0	0	0
Iron & Steel	8	23.5	20.3	20.3	18.9	1.3
Cement	15	11	8.3	8.3	7.8	0.4
Lime	9	2.7	2.1	2.1	2.1	0
Glass	28	2.6	2.0	2.0	2.0	0
Ceramic	70	1.6	1	1	1	0.1
Pulp and Paper	42	2.1	1.9	1.9	1.9	0
Other	9	0.4	0.4	0.4	0.4	0
Total	**912**	**213.6**	**265**	**265.5**	**260.9**	**4.6**

Source: DECC (2009)

More specifically installations are split out further in the UK National Allocation Plan as covering the following industries outlined above. Table 3.1 gives an overview of allocation in 2008 and of final verified emissions, therefore giving an indication of trading in each sector. Table 3.2 was released in 2010 and shows the EU ETS allocation and verification of emissions in 2008 and 2009 in the UK. Table 3.2 is shown because it gives an indication of the split between Large Electricity Producers and other combustion installations which is not given in Table 3.1. Any numerical differences between Tables 3.1 and 3.2 reflects updates from DECC.

Table 3.2: EU ETS sector allocation 2008 and 2009

Sector	Allocated 2008 MtCO2e	Allocated 2009 MtCO2e	Total Allocated MtCO2e	Verified 2008 MtCO2e	Verified 2009 MtCO2e	Total Verified MtCO2e	net shortfall/ surplus
Large Electricity Producers sector	108.3	108.3	216.6	173.8	151.1	324.9	-108.3
Combustion installations (not power sector)	46.5	46.5	93.0	37.8	36.8	74.6	18.4
Mineral oil Refineries	18.7	18.7	37.4	17.5	16.7	34.2	3.2
Coke Ovens	0.1	0.1	0.1	0.0	0.0	0.1	0.0
Iron & Steel	24.2	24.2	48.4	20.7	16.3	37.0	11.4
Cement	12.0	12.0	24.0	10.0	6.8	16.8	7.2
Glass	2.4	2.4	4.8	1.9	1.6	3.5	1.3
Ceramic	1.5	1.5	3.0	1.0	0.6	1.6	1.4
Pulp and Paper	2.0	2.0	4.0	1.8	1.6	3.4	0.6
Other	0.2	0.2	0.4	0.4	0.3	0.7	-0.3
total	**215.9**	**215.9**	**431.7**	**264.9**	**231.8**	**496.8**	**-65.1**

Source: DECC (2010c)

The EU ETS in the UK is dominated by these combustion installations. The largest emitters of CO_2 in the UK are combustion installations which can be classified as power stations or non-power stations. These combustion installations are the various industries in the economy which produce energy, as electricity or heat. Combustion installations in the EU ETS includes all the large power stations, in particular the Large Electricity Producers (LEPs), but also large combusting sources from specific industries of "Food and Drink" such as dairies, breweries or distilleries. Table 3.1

shows that LEPs account for 50% of total UK allocations of the EU ETS and in 2008 they were responsible for 66% of verified emissions.

The next largest sector in terms of the number of installations covered is the “Ceramic” sector which had 70 separate installations and then “Pulp and Paper” which had 42 installations covered by the EU ETS in 2008. The second column of Table 3.1 importantly shows the actual allocated allowances to each subheading sector in 2008. As expected the majority of allowances go to combustion installations, around 70% of total allowances. The “Iron and steel” and the “Mineral oil refineries” sectors appear to be the next largest sectors in terms of allocated allowances under the UK cap with around 11% and 8.7% of total allowances respectively. Then the “Cement” sector gets about 5% of the total UK allocation under the EU ETS. The next column of Table 3.1 shows the actual verified emissions for 2008. The main point to note is that all sectors except combustion installations emitted less than or equal to their allocation. However, combustion installations managed to emit considerably more than their initial allocation, equivalent to around 40% of their original allocation. Combustion appears to be targeted with the strictest allocation because it is considered by the EU to be the sector least open to international competition. Given this tight allocation it may also be the case that UK combustion is particularly dirty and thus requires significant purchases of allowances. Overall in 2008 the UK purchased credits worth 51.4 $MtCO_2e$, all of which must have been purchased by a combination of combustion installations. The final two columns of Table 3.1 show the split of credits surrendered between EU ETS credits (EUAs) and Kyoto credits (CERs). These show that in 2008 the Kyoto credits surrendered were less than 2% of all credits.

In deciding what IO sectors should be considered traded or non-traded in terms of the EU ETS I had to take various considerations into account. Coverage of the EU ETS is not straight-forward to apply to the economic account SIC codes as the EU ETS applies to emissions-intensive installations within an industry and not necessarily an entire industry. The EU ETS classifies installations together based upon their production process while the IO table groups together economic activities by the main product of each activity. Also, the coverage of the scheme evolves over time as more types of installations were included between Phase 1 and 2.

Another important consideration when attempting to map the economic and EU ETS sectors is that many installations are only covered by the EU ETS if they are over a certain capacity e.g. above 20MW and so smaller installations are excluded from the scheme as compliance may be too onerous a burden. There is not a detailed breakdown of this type of information for all industries and therefore I have to take an “all or nothing” approach for each industry. This will lead to cases where a sector such as “Food and Drink” may be treated by us as being covered by the EU ETS, even though only a few installations are actually part of it in practice. Also, non-power sector combustion installations, in particular, are not always easily matched to single IO sectors because they may span across several possible industries or may not be sold on to final users e.g. a generator for a hospital which it owns but which is also used by surrounding businesses.

Comparing the DECC data in Table 3.2 for 2008 with the ONS Environmental Accounts data used gives an indication of these issues. It is expected that carbon emissions by installations covered by the scheme would be lower than the total emissions by the whole sector. For instance, the verified 2008 emissions for LEPs are 173.8 $MtCO_2e$ while the total ONS emissions in 2008 for all electricity production are 183.4 $MtCO_2e$. This difference may be down to the exclusion of small generators in the DECC EU ETS data but included in the overall ONS UK emissions data. Combustion installations out with the power sector have emissions of 37.8 $MtCO_2e$ and this will be made up of installations within numerous IO sectors that have their own combustion facilities such as hospitals, manufacturers and universities. Table D1 in Appendix D lists the sectors of all 781 of the combustion installations in the UK for Phase 1 that are part of the scheme. While only 123 installations are power stations these will contribute significantly to the total emissions (ILEX, 2005). This gives an indication of the variety of sectors which all come under the combustion heading of the EU ETS. Therefore an attempt was made to match the activities listed in Table D1 with economic account sectors in the IO table such as “Food and drink”, "Vehicle manufacture", "Chemicals", "Mining and quarrying", "Services" and "Textiles". In fact the largest number of combustion installations is in the "Services" sector which has 208 installations. Although these do not contribute substantially to emissions they do account for around a quarter of all the installations in the UK and include a large variety of sectors such as health, education and retail. None of these sectors will be 100% covered by the scheme in practice but there are no available data to check against the Environmental Accounts.

"Iron and steel" has EU ETS verified emissions of 20.7 $MtCO_2e$ in 2008 while the ONS total emissions figure is 21.8 $MtCO_2e$ for the same sector, suggesting that almost all of the sector is included in the scheme and for simplicity it is assumed to be 100% covered. The "Cement" sector has EU ETS verified emissions of 10 $MtCO_2e$ while the EA for the cement economic sector is 9.9 $MtCO_2e$, it therefore appears to be completely covered. The "Glass", "Ceramics", and "Mineral oil refineries" EU ETS sectors have verified emissions of 1.9, 1, and 17.5 $MtCO_2e$ respectively however, the economic sectors of "Glass and glass products", "Ceramic goods" and "Refined petroleum products" have total sectoral emissions in the EA of 1.5, 0.3 and 15.3 $MtCO_2e$. All of these are less than the EU ETS total for that year which suggests discrepancies between the data sources. It is assumed that all these sectors are wholly covered in the analysis. "Pulp and Paper" verified emissions are only 1.8 compared to EA total of 4.2 suggesting that only 43% of the sector's emissions are covered by the EU ETS.

Therefore, given these constraints and issues, the methodology that is used is to adopt a similar total coverage of emissions as that of the traded sector EU ETS in practice, which is 48% of total UK CO_2 emissions. This amounts to 302796 thousand tonnes of carbon dioxide in 2004. This was achieved by deciding first what sectors are wholly covered by the EU ETS such as the "Electricity", "Glass and glass products", "Ceramic goods" and "Iron and steel" sectors etc. listed above. Sectors that are partially covered by the scheme are then added such as "Pulp and paper" and from non-power sector combustion installations such as "Food and Drink", "Textiles", "Chemicals" and "Motor vehicles" until arriving at a figure of roughly 48% of UK CO_2 emissions in the database.

Another possible method, which is used by DECC in their analysis of the EU ETS, is to apply a carbon tax to each sector of the economy based upon the percentage of emissions covered by the EU ETS within a sector. For example, if every installation in an industry is covered by the EU ETS, then an appropriate carbon tax is applied at 100% of its value i.e. the whole tax is applied. However, if only 30% of emissions in a particular sector are traded in the EU ETS, and 70% of emissions are not covered by the scheme, then a carbon tax rate of 30% is applied to that sector.[79]

Given a lack of complete sectoral level data, together with a desire to ease the simulation procedure, an "*all or nothing*" approach was adopted whereby each industry in the 123 sector IO table is treated "*as if*" it is either all covered or all uncovered by the EU ETS. Therefore while emissions from some industries. More work is required in future to attempt to identify the EU ETS sectors more accurately using micro level data but ultimately, due to the nature of the scheme allowing exemption for smaller installations and incomplete coverage of sectors, some assumptions will be necessary. This 'all or nothing' approach may have implications for the results of certain policy shocks and therefore the effects of a EU ETS carbon price may be over or under-exaggerated in comparison to what would happen in practice for sectors that have emissions which are only partially covered by the scheme. However, the carbon tax in chapter 5 is applied to all sectors and therefore the 'all or nothing' aggregation is not an issue in this thesis but may become relevant once future simulations are undertaken which consider policy instruments distinguished by sector.

Once the EU ETS sectors were identified to the best of my ability, the UKIO 2004 was aggregated from the 66 economic/environmental matching sectors to 25 economic sectors listed in Table 3.3, of which 13 are traded sectors and 12 are non-traded sectors in terms of EU ETS. This aggregation was necessary in terms of

[79] The data that DECC use in applying carbon tax rates hasn't been made public

simplifying the analysis. Aggregation to roughly the same number of traded and non-traded sectors in the table allowed me to analyse the traded and non-traded sectors by easily comparing them to each other to view their importance to the UK economy and emissions through multiplier analysis. In undertaking this aggregation it was important to identify other large emitting sectors for the UK economy that were not covered by the EU ETS. "Agriculture" and "Air transport" both contribute significantly in terms of GHG emissions and so are not combined with other industries. All manufacturing not covered by the EU ETS is aggregated together as one single sector. A number of different aggregations were undertaken until I settled on the one given in Table 3.3. While there will be some inevitable bias from taking the sectoral aggregation from 123 to 25 economic sectors, the main '*big hitting'* sectors in terms of emissions are captured in this aggregation and give an overview of the main industries included in the EU ETS as well as the large emitting sectors in the non-traded sector.

There are nine final demand sectors in the table for Households, Non Profit institutions serving households (NPISHs), Central and Local government, three Gross fixed capital formation (GFCF) sectors, and exports to EU and non-EU countries. The four value added components in the UKIO 2004 table are imports from rest of the world, net taxes on production, compensation of employees, and gross operating surplus. The twenty-five sector input-output table is given in Table D2 of Appendix D.

Table 3.3: Mapping of 123 sectors and EU ETS

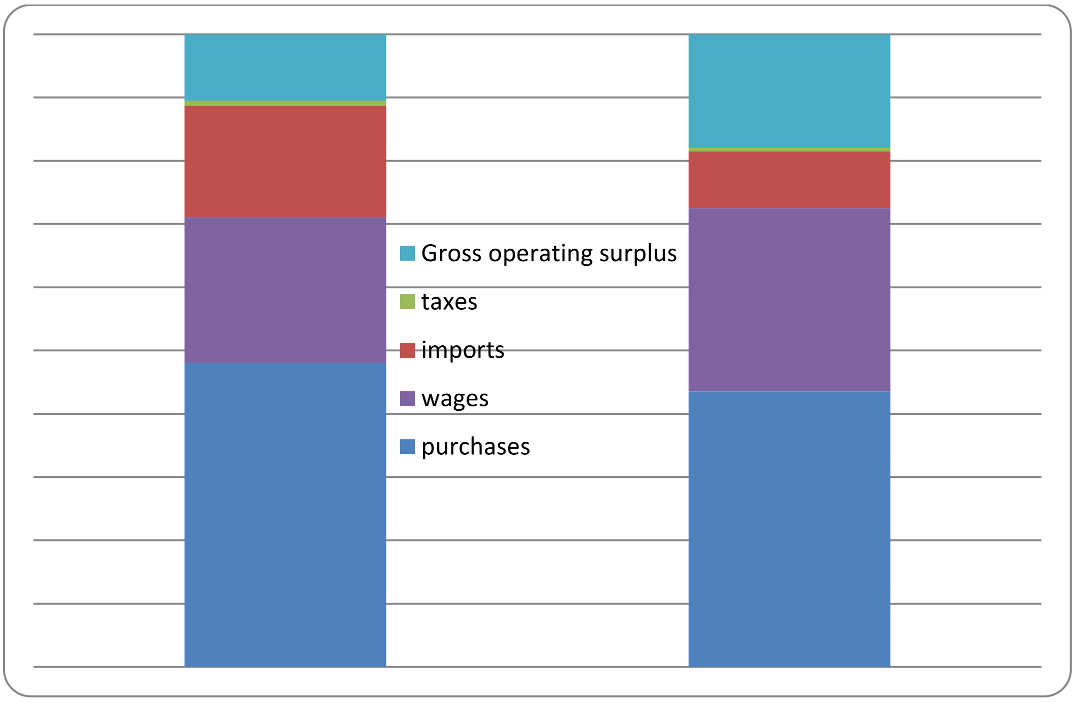
Sector Title	25 IO	123 sectors	EU ETS
Mining and quarrying	1	4-7	Y
Food and Drink	2	8-19	Y
Textiles; wearing apprrel; leather products	3	21-30	Y
Wood; Pulp and paper; Printing and publishing	4	31-34	Y
Coke ovens, refined petroleum and nuclear fuel	5	35	Y
Gases and dyes; Chemicals	6	36-38	Y
Glass	7	49	Y
Ceramics	8	50	Y
Clay, cement, lime and plaster	9	51-52	Y
Concrete and Stone etc	10	53	Y
Iron and Steel; non-ferrous metals	11	54-56	Y
Motor vehicles and other transport	12	77-80	Y
Electricity production and distribution	13	85	Y
Agriculture	14	1	N
Forestry and fishing	15	2-3	N
Other Manufacturing	16	20, 39-48, 57-76, 81-84	N
Gas and water supply; Construction	17	86-88	N
Wholesale retail trade; Repair of vehicles; personal and household goods; Hotels and restaurants	18	89-92	N
Other Transport	19	93-95, 97-99	N
Air Transport	20	96	N
Finance	21	100-102	N
Real Estate, renting and business activities	22	103-114	N
Public administration and defence	23	115	N
Education; Health and social work	24	116-118	N
Other community, social and personal service; Private households with employed persons	25	119-123	N

6. RESULTS

6.1 Traded vs. non-traded overview

Figure 3.4 considers all traded sectors together and all non-traded sectors together and gives a breakdown of what their inputs are composed of in terms of gross operating surplus, wages, taxes, imports and purchases. Comparing the aggregated 25 sector IO table between traded and non-traded sectors shows that the traded sector has a higher proportion of domestic purchases with 48% of purchases coming from other sectors of UK economy compared to only 43% for the non-traded sector on average. However, the non-traded sector has a greater proportion of wages paid (29% to 23%), and so is likely more labour intensive. These are the important factors included in the following Type 1 and 2 multiplier analysis. Figure 3.4 shows that the traded sector also has roughly double the amount of imports as a percentage of total purchases that the non-traded sector has with 18% and 9% respectively. It also has a considerably higher gross operating surplus than the traded sector.

Figure 3.4: Portion of inputs by type and turnover of traded and non-traded sectors



6.2 Output Multipliers

It is possible to apply the IO model outlined earlier in this chapter to the UKIO for 2004 to look at the effects of changes in demand for certain sectors. The Type 1 and Type 2 output multipliers, derived from the Leontief matrix, are listed for all 25 sectors of the UKIO table and are presented in Table 3.4 and Figure 3.5.

Inspection of Table 3.4 reveals that the Type 1 output multipliers, which incorporate both the direct and indirect effects, range from 1.49, in the "Retail Estate" sector, up to the "Electricity" sector which has the largest Type 1 multiplier (2.3) of all UK economic sectors, whether covered by the EU ETS or not. This suggests strong backward linkages for the electricity sector. In particular, much of the "Electricity" sector's purchases are in fact from itself, as well as some "Mining", "Construction" and "Finance". Other large Type 1 multipliers include the "Forestry and fishing" sector (2.1) as well as the "Gas, water and construction" sector (2.06), both of which are non-EU ETS sectors.

Figure 3.5: Type 1 and 2 Output multipliers for UK 2004

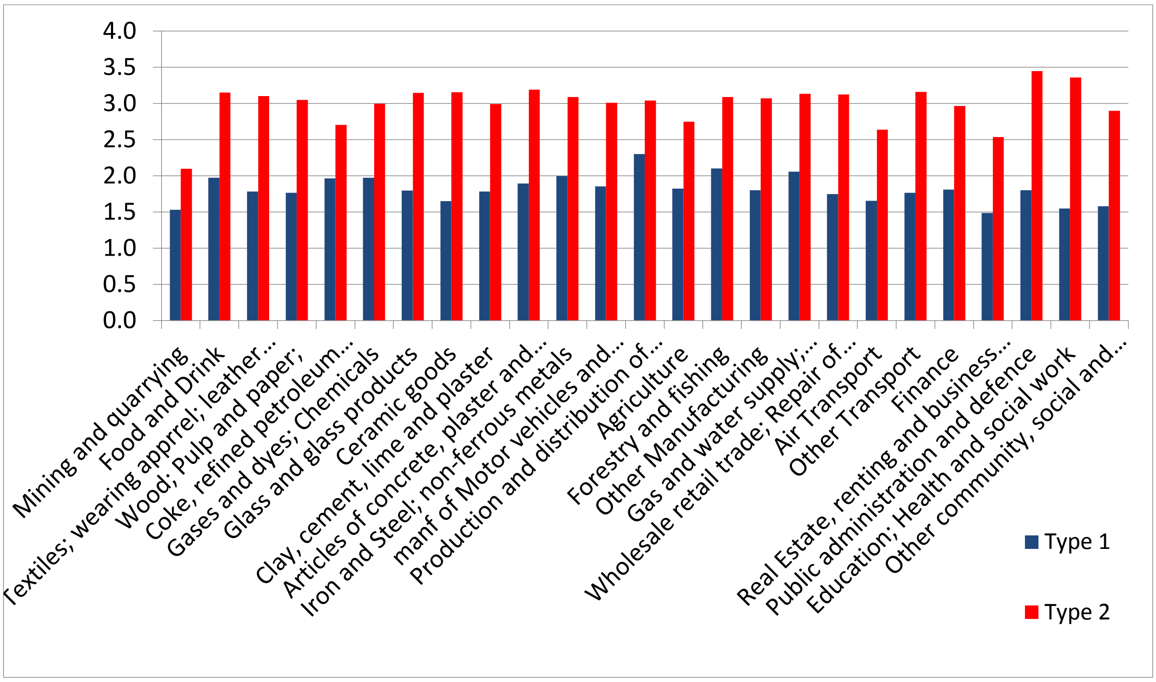


Table 3.4: Output multipliers and ranks for 25 sectors of UK economy

Output multipliers and rankings				Rank		Rank
Sector No.		Sector name	Type 1	(1-25)	Type 2	(1-25)
Traded	1	Mining and quarrying	1.532	24	2.096	25
	2	Food and Drink	1.973	6	3.152	6
	3	Textiles; wearing apprrel; leather products	1.785	15	3.103	10
	4	Wood; Pulp and paper;	1.766	17	3.050	14
	5	Coke, refined petroleum products and nuclear fuel	1.962	7	2.704	22
	6	Gases and dyes; Chemicals	1.973	5	2.996	17
	7	Glass and glass products	1.798	14	3.149	7
	8	Ceramic goods	1.649	21	3.154	5
	9	Clay, cement, lime and plaster	1.783	16	2.990	18
	10	Articles of concrete, plaster and cement	1.893	8	3.190	3
	11	Iron and Steel; non-ferrous metals	1.997	4	3.088	12
	12	manf of Motor vehicles and other transport	1.854	9	3.010	16
	13	Production and distribution of electricity	2.300	1	3.042	15
Non-traded	14	Agriculture	1.823	10	2.747	21
	15	Forestry and fishing	2.103	2	3.090	11
	16	Other Manufacturing	1.802	13	3.072	13
	17	Gas and water supply; Construction	2.056	3	3.136	8
	18	Wholesale retail trade; Repair of vehicles; household goods; Hotels and restaurants	1.748	19	3.125	9
	19	Air Transport	1.655	20	2.639	23
	20	Other Transport	1.763	18	3.160	4
	21	Finance	1.811	11	2.966	19
	22	Real Estate, renting and business activities	1.487	25	2.534	24
	23	Public administration and defence	1.803	12	3.446	1
	24	Education; Health and social work	1.546	23	3.360	2
	25	Other community, social and personal service	1.582	22	2.897	20

However, once the household sector is made endogenous to the model, the Type 2 multipliers range from 2.1 to 3.45. The five largest output multipliers are now completely different sectors of the economy. The multiplier for “Electricity” is only the 15th largest of all 25 sectors in this instance. Once households are endogenous, then it is sectors such as “Public administration” and “Education and health” that have the most significant multiplier effects. This is because these sectors are highly labour-intensive, they have the highest percentage of inputs going to employee compensation at 43% and 53% respectively. Therefore the wages paid increase household incomes and, in the case where consumption is endogenous, this in turn increases household consumption. The extent of the increase is determined by the coefficient for each sector which is calculated by dividing household purchases from each sector by total household income from wages paid. The scale of the difference between Type 2 and Type 1 multipliers is large for the “Other transport” sector, probably because transport spends significantly on wages as an input as labour is an essential part of all transport business. Capital-intensive sectors generally rank less highly, such as “Iron and steel”, under these Type 2 conditions once households are endogenous.

Table 3.5 shows the mean and standard deviation of the output multipliers for all sectors as well as broken down into traded and non-traded sector totals. The average Type 1 (Type 2) output multiplier across all sectors was 1.82 (3.00). The standard deviation is increased with Type 2 multipliers where households are endogenous compared to the Type 1 case. It is possible also to consider separately the multipliers for traded and non-traded sectors. The mean of the output multipliers for EU ETS sectors was 1.87 (2.98) compared to 1.77 (3.01) for non-traded sectors and so it seems that under IO the traded sector in general has a greater effect on gross output of the economy under the closed Leontief system but that the non-traded sector has a slightly greater output effect with endogenous households. This is reinforced when the output multipliers are decomposed by weighting each sector based on its contribution to final demand of the traded and non-traded sectors, respectively. In doing this we obtain a traded sector multiplier of 1.88 (2.95) and a non-traded sector output multiplier of 1.71 (3.07).

Table 3.5: Descriptive statistics of output multipliers

Descriptive Stats	**All sectors**		**Traded**		**Non-traded**	
Output multipliers	Type 1	Type 2	Type 1	Type 2	Type 1	Type 2
Average	1.818	2.996	1.867	2.979	1.765	3.014
Standard deviation	0.190	0.278	0.188	0.293	0.185	0.273

Looking specifically at EU ETS traded industries in Table 3.4, the “Electricity” sector has the largest Type 1 multiplier but the largest Type 2 is the sector of “Articles of concrete, plaster and cement”. The “Ceramic goods” sector is interesting as it is the second smallest Type 1 but second largest Type 2 of all traded sectors. This appears to be because ceramics has the highest percentage of gross output paid to wages of all the EU ETS sectors at 42%.

Concentrating on the non-traded sectors in Table 3.4, the largest Type 1 output multipliers are “Forestry and fishing” (2.1), “Gas, water and construction” (2.06) and “Agriculture” (1.82). All of these have considerable domestic purchases and so are heavily embedded within the UK economy. “Finance and public administration” also has a large output multiplier for this same reason. The non-traded sector has quite substantial differences between Type 1 and 2 multipliers.

If we concentrate on the output multipliers for the nine final demand sectors, displayed in Table 3.6, the largest Type 1 multiplier is for Changes in Inventories (1.91), although the actual amount of final demand is very small for it in comparison to the other final demands. The largest Type 2 final demand-output multiplier is for Central Government (3.39). Both EU and non-EU exports both have fairly large Type 1 multipliers compared to other final demand sectors but have relatively smaller Type 2 multipliers as they rank less highly among final demand sectors.

Table 3.6: Final demand output multipliers

Final demand-output multipliers		
final demand group	Type 1	Type 2
Households	1.718	N/A
NPISHs	1.554	3.233
Central Government	1.665	3.389
Local Government	1.628	3.345
GFCF	1.897	3.019
Change in Inventories	1.911	3.029
exports EU	1.766	2.925
exports Non-EU	1.737	2.912

6.3 Employment and GVA multipliers

Table 3.7 gives the Type 1 and 2 employment-output multipliers for all twenty-five economic sectors. These give the number of jobs (in thousands) that would be created if the final demand for a sector was to increase by £1 million. The highest ranked Type 1 employment multipliers are sectors 24 “Education; health and social work” and 18 “Wholesale retail trade; Hotels and restaurants” which have multipliers of 0.027 and 0.024 respectively. Therefore if there was an increase in final demand for education of £1 million we would expect twenty-seven extra jobs to be required throughout the economy. These results seem sensible given that the jobs in these industries are predominantly done people trained staff. Both of these sectors are non-traded.

Table 3.7: Employment output multipliers (thousand jobs per £1m increase in final demand)

Employment-output multipliers and rankings						
Sector No.		Sector name	Type 1	Rank (1-25)	Type 2	Rank (1-25)
Traded	1	Mining and quarrying	0.006	25	0.013	25
	2	Food and Drink	0.016	14	0.029	11
	3	Textiles; wearing apprrel; leather products	0.022	3	0.036	5
	4	Wood; Pulp and paper;	0.016	12	0.031	9
	5	Coke, refined petroleum products and nuclear fuel	0.007	24	0.015	24
	6	Gases and dyes; Chemicals	0.010	22	0.022	22
	7	Glass and glass products	0.018	8	0.033	6
	8	Ceramic goods	0.021	5	0.037	4
	9	Clay, cement, lime and plaster	0.014	19	0.027	16
	10	Articles of concrete, plaster and cement	0.016	13	0.031	10
	11	Iron and Steel; non-ferrous metals	0.015	17	0.027	17
	12	manf of Motor vehicles and other transport	0.014	18	0.027	18
	13	Production and distribution of electricity	0.008	23	0.017	23
Non-traded	14	Agriculture	0.018	6	0.029	12
	15	Forestry and fishing	0.017	9	0.028	14
	16	Other Manufacturing	0.017	11	0.028	15
	17	Gas and water supply; Construction	0.016	15	0.040	2
	18	Wholesale retail trade; Repair of vehicles; household goods; Hotels and restaurants	0.024	2	0.022	21
	19	Air Transport	0.011	21	0.032	7
	20	Other Transport	0.017	10	0.027	19
	21	Finance	0.014	20	0.027	20
	22	Real Estate, renting and business activities	0.015	16	0.039	3
	23	Public administration and defence	0.021	4	0.047	1
	24	Education; Health and social work	0.027	1	0.032	8
	25	Other community, social and personal service	0.018	7	0.028	13

The traded sectors with the highest employment multipliers are “Textiles” (which will only be partially covered in practice) which ranked third overall with a multiplier of 0.022 and also “Glass” and “Ceramics” which ranked eighth and fifth with 0.018 and 0.021. “Mining and quarrying” has the lowest employment multiplier of any sector. For the Type 2 employment-output multipliers the largest are in the “Public admin and defence” sector and in the “Gas and water supply; construction” sector. These are very labour-intensive and have higher effects when households are endogenous to the model.

Table 3.8 gives the gross value-added output multipliers for each sector. The sectors which have high value-added to output ratios have a larger multiplier effects when final demand is increased. The top-ranked sectors for Type 1 GVA multipliers are “Real Estate” and “Finance” which have considerable value-added inputs as well as output multipliers.

Table 3.8: GVA-output multipliers and rankings

GVA-output multipliers and rankings				Rank		Rank
Sector No.		Sector name	Type 1	(1-25)	Type 2	(1-25)
Traded	1	Mining and quarrying	0.888	4	1.172	22
	2	Food and Drink	0.746	18	1.341	16
	3	Textiles; wearing apprrel; leather products	0.713	21	1.379	14
	4	Wood; Pulp and paper;	0.787	17	1.436	12
	5	Coke, refined petroleum products and nuclear fuel	0.643	22	1.018	25
	6	Gases and dyes; Chemicals	0.596	25	1.113	24
	7	Glass and glass products	0.788	16	1.471	8
	8	Ceramic goods	0.797	15	1.557	5
	9	Clay, cement, lime and plaster	0.834	11	1.444	11
	10	Articles of concrete, plaster and cement	0.797	14	1.453	10
	11	Iron and Steel; non-ferrous metals	0.611	24	1.162	23
	12	manf of Motor vehicles and other transport	0.611	23	1.195	21
	13	Production and distribution of electricity	0.864	7	1.239	19
Non-traded	14	Agriculture	0.817	13	1.284	17
	15	Forestry and fishing	0.848	10	1.346	15
	16	Other Manufacturing	0.719	20	1.404	13
	17	Gas and water supply; Construction	0.859	8	1.583	3
	18	Wholesale retail trade; Repair of vehicles; household goods; Hotels and restaurants	0.887	5	1.226	20
	19	Air Transport	0.729	19	1.561	4
	20	Other Transport	0.855	9	1.492	7
	21	Finance	0.909	2	1.466	9
	22	Real Estate, renting and business activities	0.937	1	1.659	2
	23	Public administration and defence	0.829	12	1.812	1
	24	Education; Health and social work	0.896	3	1.535	6
	25	Other community, social and personal service	0.870	6	1.272	18

6.4 GHG-output and CO_2-output multipliers

I calculated Type 1 and 2 GHG-output multipliers and CO_2-output multipliers for each sector of the economy and these are reported in Tables 3.9 and 3.10. These were calculated using vectors of GHG and CO_2 coefficients taken and aggregated from the Environmental Accounts (ONS, 2010a) for 2004 which link emissions for each sector to that sector's output level. For each sector, these multipliers detail the amount of GHGs and CO_2 generated in the production of output to meet £1million of demand from that sector. The GHGs are calculated in tonnes of carbon dioxide equivalent.

The largest multipliers for GHGs came from the "Electricity" sector with Type 1 (Type 2) of 8134 (8487) tonnes per £1 million final demand. These results suggest that for an increase in demand for electricity of £100 million would result in 813400 tonnes of GHGs being emitted into the atmosphere by the UK. Looking at the CO_2-output multipliers, again "Electricity" has the highest Type 1 (7993) and 2 multipliers (8297). This serves to underline this sector's importance in reducing greenhouse gas and carbon dioxide emissions. It also strengthens the case for disaggregation of the sector to identify separately the contributions of the (very heterogeneous) electricity generating technologies to provide a richer model. Allan *et al* (2007a) attempted to disaggregate the electricity sector in Scotland into various generating technologies, although they only consider output multipliers.

Table 3.9: GHG-output multipliers (Tonnes of GHG generated in the production of output to meet a £1million increase in sector demand)

GHG-output multipliers and ranking				Rank		Rank
Sector No.		Sector name	Type 1	(1-25)	Type 2	(1-25)
Traded	1	Mining and quarrying	1229	8	1497	10
	2	Food and Drink	730	12	1292	14
	3	Textiles; wearing apprrel; leather products	477	16	1106	15
	4	Wood; Pulp and paper	436	19	1049	19
	5	Coke, refined petroleum products and nuclear fuel	1724	6	2078	6
	6	Gases and dyes; Chemicals	1311	7	1798	7
	7	Glass and glass products	1104	9	1748	8
	8	Ceramic goods	634	13	1352	11
	9	Clay, cement, lime and plaster	7817	2	8393	2
	10	Articles of concrete, plaster and cement	881	10	1500	9
	11	Iron and Steel; non-ferrous metals	2486	5	3007	5
	12	manf of Motor vehicles and other transport	367	20	918	23
	13	Production and distribution of electricity	8134	1	8487	1
Non-traded	14	Agriculture	2898	4	3338	4
	15	Forestry and fishing	861	11	1332	12
	16	Other Manufacturing	459	17	1065	18
	17	Gas and water supply; Construction	480	15	995	21
	18	Wholesale retail trade; Repair of vehicles;household goods; Hotels and restaurants	301	21	958	22
	19	Air Transport	3024	3	3493	3
	20	Other Transport	630	14	1296	13
	21	Finance	193	23	744	24
	22	Real Estate	115	25	614	25
	23	Public administration and defence	291	22	1075	17
	24	Education; Health and social work	182	24	1047	20
	25	Other community, social and personal service	448	18	1076	16

I now turn to considering the CO_2 multipliers listed in Table 3.10. The sector with the second largest Type 1 and 2 CO_2-output multipliers is the “Clay, cement, lime and plaster” sector. This sector has multipliers almost as large as electricity for both GHGs (7817, 8393) and CO_2 (7715, 8210). The “Air transport” sector is also very important (2976, 3379). Type 1 multipliers for CO_2 and GHG multipliers are also shown graphically in Figure 3.6 and for Type 2 in Figure 3.7 to show which sectors are particularly emissions intensive.

As expected the sector which has a small CO_2 multiplier but large GHG multiplier is the Agriculture sector (2898, 3338) which reflects the considerable methane and nitrous oxide emissions from this sector. Agriculture ranks only at 13 (Type 1) and 18 (Type 2) in terms of CO_2 multipliers but has the fourth largest GHG multiplier for both Types 1 and 2. This reflects the nature of the agriculture sector, which is emissions intensive but not due to CO_2. Given the UK’s Kyoto commitment and the fact that many of these other GHGs are considerably stronger than CO_2 in terms of environmental impact,[80] it is clear that appropriately designed policies for reducing emissions from agriculture are needed in the UK. To put it another way, Type 1 and 2 multipliers tend to be similar when compared across gases, except for what appears to be the unique case of agriculture.[81]

[80] One tone of methane has 23 times the global warming potential of carbon dioxide over 100 years
[81] Although this conclusion does depend on the level of sectoral aggregation undertaken and perhaps another individual industry may also have larger GHGs than CO_2 emissions. However, it is clear that there is none with as large GHG emissions as Agriculture.

Table 3.10: CO_2-output multipliers and ranking for UK in 2004. Tonnes of CO_2 generated for output to meet a £1million increase in sectoral demand

CO2-output multipliers and ranking				Rank		Rank
Sector No.		Sector name	Type 1	(1-25)	Type 2	(1-25)
Traded	1	Mining and quarrying	1000	8	1230	9
	2	Food and Drink	435	15	918	17
	3	Textiles; wearing apprrel; leather products	451	14	991	13
	4	Wood; Pulp and paper	413	17	939	15
	5	Coke, refined petroleum products and nuclear fuel	1599	5	1904	5
	6	Gases and dyes; Chemicals	1121	6	1541	7
	7	Glass and glass products	1070	7	1624	6
	8	Ceramic goods	600	12	1217	10
	9	Clay, cement, lime and plaster	7715	2	8210	2
	10	Articles of concrete, plaster and cement	845	9	1377	8
	11	Iron and Steel; non-ferrous metals	2386	4	2834	4
	12	manf of Motor vehicles and other transport	345	19	819	21
	13	Production and distribution of electricity	7993	1	8297	1
Non-traded	14	Agriculture	529	13	908	18
	15	Forestry and fishing	795	10	1200	11
	16	Other Manufacturing	411	18	932	16
	17	Gas and water supply; Construction	420	16	863	20
	18	Wholesale retail trade; Repair of vehicles; household goods; Hotels and restaurants	254	21	818	22
	19	Air Transport	2976	3	3379	3
	20	Other Transport	606	11	1179	12
	21	Finance	179	22	652	24
	22	Real Estate	104	25	533	25
	23	Public administration and defence	269	20	943	14
	24	Education; Health and social work	164	24	908	19
	25	Other community, social and personal service	173	23	712	23

Figure 3.6: Type 1 CO_2-output and GHG-output multipliers (Tonnes of CO_2/GHG per £1m in final demand)

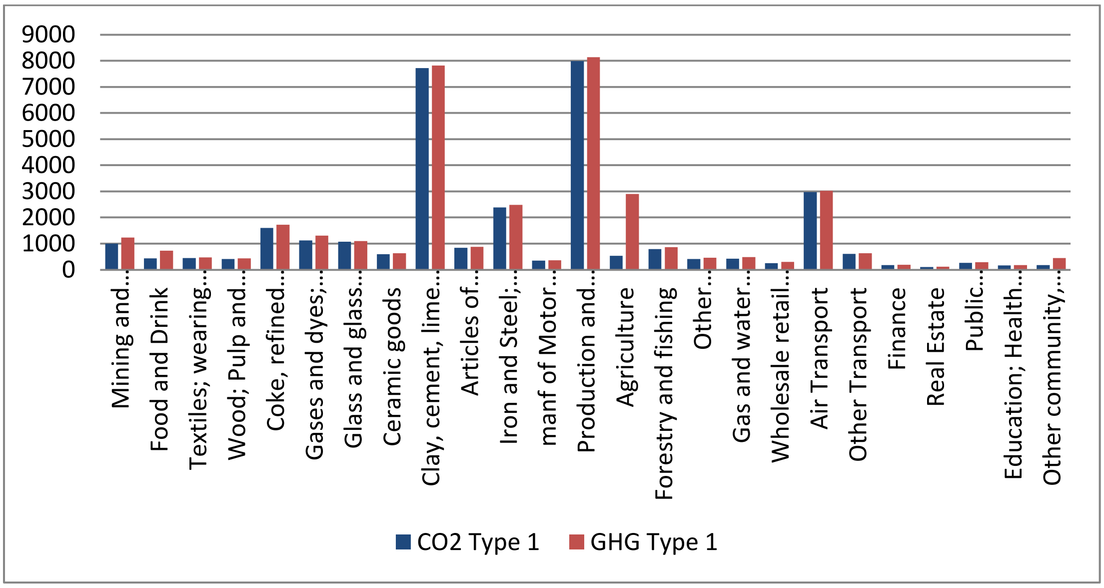
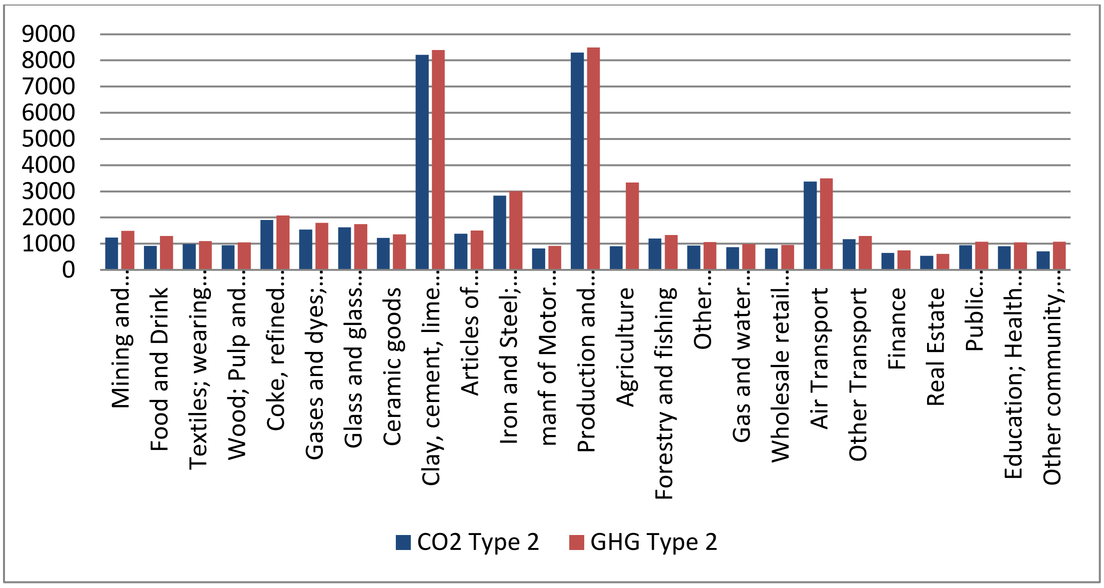


Figure 3.7: Type 2 CO_2 and GHG multipliers (Tonnes of CO_2/GHG per £1m in final demand)



The Environmental Accounts detailed the amount of CO_2 produced by households and so an estimated coefficient for household emissions can be made and used when calculating Type 2 multipliers. These are 1201 and 1033 for GHGs and CO_2 respectively. In general, once households are endogenous this increases the GHG or

CO_2 multiplier of each sector quite substantially. However, it does not appear to change the order of ranking of the sectors in any significant way.

If we look specifically at the difference between the EU ETS traded and non-traded sectors of the UK economy we can view one reason why these sectors were chosen to be covered by the trading scheme. From Table 3.9 the average Type 1 (Type 2) GHG multiplier for the traded sector is 2102 (2633) compared to only 823 (1419) for the non-traded sector. However, the EU ETS currently only pertains to CO_2 emissions and so it is more appropriate to view these alone. The top half of Table 3.10 shows the CO_2 multipliers for only the EU ETS traded sectors and that the average CO_2-output multiplier for the traded sector is 1998 (2454) as opposed to the non-traded sector average of only 573 (1086) taken from the multipliers shown in the bottom section of Table 3.10.

Table 3.11: Final demand-GHG and CO_2 multipliers

final demand group	Final demand-GHG multipliers		Final demand-CO2 multipliers	
	Type 1	Type 2	Type 1	Type 2
Households	820	N/A	704	N/A
NPISHs	239	1039	165	853
Central Government	238	1061	213	920
Local Government	239	1058	197	901
GFCF	418	953	353	813
Change in Inventories	507	1041	438	896
exports EU	624	1177	545	1019
exports Non-EU	517	1078	455	937

Table 3.11 shows the final demand CO_2 multipliers for all of the nine final demand sectors which tell us the contribution in tonnes of CO_2 generated per £1m

expenditure of final demand on local goods. This is achieved by multiplying the vector of CO_2 multipliers by the final demand matrix. Final demand contributions are almost identical for GHG emissions and for CO_2 emissions across both open and closed models therefore only CO_2 results are reported here. The largest Type 1 final demand-CO_2 multipliers are for Households (820) followed by EU exports and then non-EU exports. The largest Type 2 final demand-CO_2 multipliers are for EU exports but the range between multipliers is considerably smaller for Type 2 final demand multipliers. Figure 3.8 shows that household final demand accounts for 62% of UK CO_2 emissions. Combined exports then contribute towards 21% of all CO_2.

Figure 3.8: **Total UK CO_2 supported by each sector of final demand**

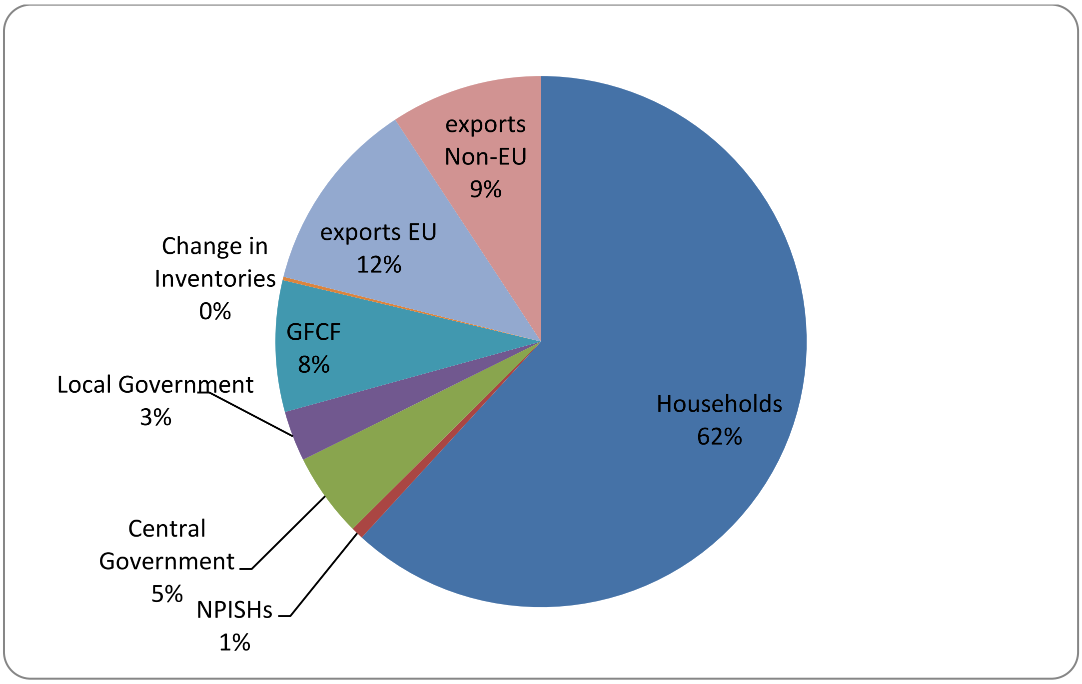


Figure 3.9 shows that when CO_2 attributed to final demand is split between the traded and non-traded sectors then it is actually final demand for non-traded sectors that contributes towards 72% of total UK carbon dioxide emissions while traded sectors account for the other 28%. This is calculated by multiplying the vector of traded sector CO_2 multipliers by the traded sector final demand matrix, and the same calculation undertaken for the non-traded sector. These results show that while traded sector emissions are responsible for 48% of total emissions it is final demand

for the non-traded sectors that are responsible for almost three quarters of total emissions.

Figure 3.9: Percentage of CO_2 emissions supported by traded and non-traded final demand

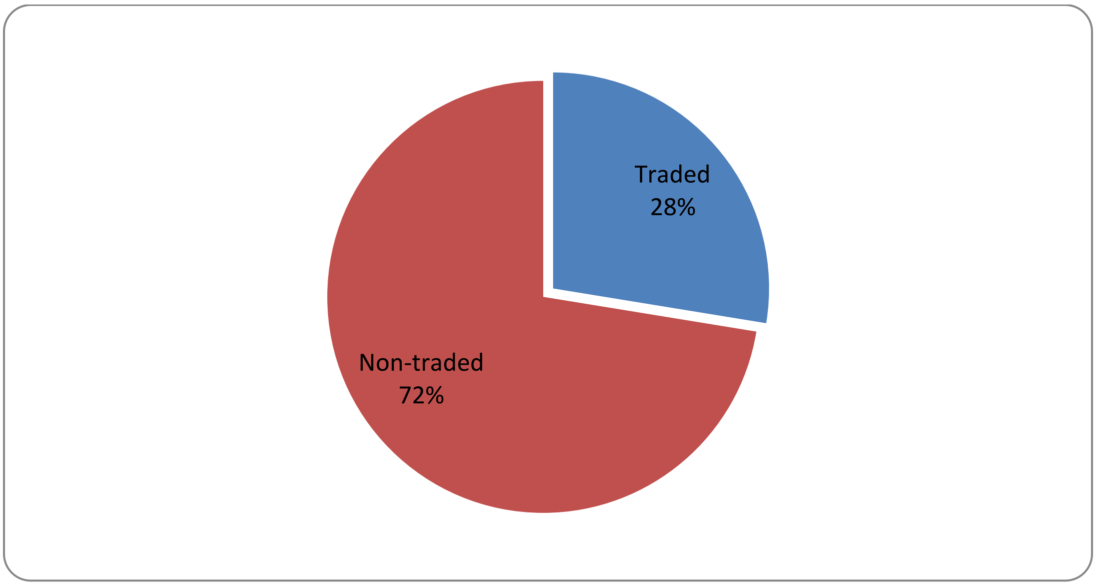


Table 3.12 below gives the coefficients which identify the relationship between emissions and employment and between emissions and GVA. The sector which has the largest CO_2 and GHG emissions per employee ratio is electricity sector which emits just over 3000 tonnes of CO_2/GHG per person employed. ‘Iron and steel’, ‘Coke; Petroleum and nuclear fuel’ and ‘Cement’ sectors also have relatively high levels of emissions per employee as do the non-traded sectors of ‘Agriculture’ and the various transport sectors. The ‘Finance’ and ‘Real Estate’ sectors only produce about one tonne of CO_2 per person employed in the sector. The sector with the largest ratio of emissions to GVA is again electricity. This is most because the level of emissions for the electricity sector is considerably greater than any other single economic sector.

Table 3.12: Emissions per employee and emissions per £m GVA

Sector No.		Sector name	CO2 (tonnes) per employee	GHG (tonnes) per employee	CO2 (tonnes) per £m GVA	GHG (tonnes) per £m GVA
Traded	1	Mining and quarrying	398	510	1,207	1,546
	2	Food and Drink	21	21	474	480
	3	Textiles; wearing apprrel; leather products	17	17	658	678
	4	Wood; Pulp and paper;	18	18	378	386
	5	Coke, refined petroleum products and nuclear fuel	754	763	9,012	9,118
	6	Gases and dyes; Chemicals	196	244	2,836	3,533
	7	Glass and glass products	55	56	1,359	1,380
	8	Ceramic goods	19	20	579	608
	9	Clay, cement, lime and plaster	932	942	14,931	15,085
	10	Articles of concrete, plaster and cement	16	16	340	351
	11	Iron and Steel; non-ferrous metals	330	343	10,403	10,791
	12	manf of Motor vehicles and other transport	9	9	217	222
	13	Production and distribution of electricity	3,032	3,059	18,673	18,840
Non-traded	14	Agriculture	28	248	653	5,760
	15	Forestry and fishing	31	34	656	711
	16	Other Manufacturing	12	15	318	383
	17	Gas and water supply; Construction	10	15	187	264
	18	Wholesale retail trade; Repair of vehicles; household goods; Hotels and restaurants	3	4	100	120
	19	Air Transport	475	480	6,469	6,538
	20	Other Transport	38	39	786	802
	21	Finance	1	1	14	16
	22	Real Estate, renting and business activities	1	2	21	23
	23	Public administration and defence	6	7	189	193
	24	Education; Health and social work	2	2	65	68
	25	Other community, social and personal service	4	24	92	506

7. CONCLUSION AND EXTENSIONS

Governments often have goals which include both increasing economic growth and reducing environmental harm. The above analysis gives an indication of which sectors are important for the UK in terms of economic output as well as for emissions reductions. In particular this multi-sector analysis shows that the multiplier effect of many sectors can be important to overall output and emissions levels when responding to changes in final demands.

I distinguish the EU ETS traded sectors in order to understand what sectors of the UK economy are already targeted by policy in the form of a carbon price. From the analysis undertaken a few economic sectors stand out as being important in terms of the UK's emissions which contribute to climate change. Under the assumption of exogenous households there are four main sectors which have high output multipliers as well as GHG and CO_2 multipliers – "Electricity", "Iron and steel", "Coke, refined petroleum and nuclear fuel" and "Chemicals", all of which are EU ETS traded sectors. It is clear that "Electricity" is an incredibly important sector in terms of output and particularly in terms of GHG emissions as it has the largest output, GHG and CO_2 multipliers. Given the importance of electricity in terms of its significant effect on emissions in production of goods in the UK economy, it is necessary to consider this sector in greater detail. Specifically it is important to disaggregate the electricity sector in order to distinguish between generation and other activities and also to separately identify alternative generating technologies. This would allow a more in depth analysis. In particular, we may be able to quantify the effects policies aimed at dirty technologies, such as a carbon tax, which would encourage substitution between technologies with different emissions-intensities.

It is essential to disaggregate the electricity sector further in order to analyse and understand the heterogeneity of the sector since this is important to correctly model output and emissions. There is therefore a need to differentiate among the generation technologies and this is undertaken next in Chapter 4. This is crucial because the technologies have radically different carbon intensities. In particular this will also allow modelling of policies intended for different electricity generating technologies, such as the taxes on emissions from coal and gas, and support for low carbon technologies such as nuclear and wind.

The other sectors which, under Type 1 analysis, have high output, GHG and CO_2 multipliers are the "Iron and steel" sector, the "Coke, petroleum, and nuclear fuel" sector, and also the "Gases, dyes and chemicals" sector. Any reduction in output of these sectors will have knock-on effects for the rest of the economy and therefore methods to reduce emissions within these sectors without decreasing production must be utilised and developed. All of these are covered by the EU ETS. This shows the importance of the EU ETS as a policy tool in reducing UK CO_2 emissions especially given that it covers just under half of total UK carbon dioxide emissions.
Once households are considered endogenous to the model then no particular industry stands out as having consistently large multipliers. Agriculture emits significant GHG emissions, where many of the gases are difficult to measure and so new policies to reduce emissions must be designed specifically with this sector and other greenhouse gases in mind.

The EU ETS could be harmonised with IO analysis which considers environmental policies by mapping of EU ETS emissions to specific SIC codes. This would require DECC and the ONS to publish data which stated specifically what SIC sector each UK installation in the EU ETS belongs to and the total emissions from each installation in line with total emissions from that SIC sector. For example, it may then be possible to specifically say that 43% of the total emissions from the "Pulp and paper" sector are from the ten specific installations which are considered covered under the EU ETS. Or it may be possible to say how much of total "Services" emissions are accounted for by the 208 services installations that are part of the EU ETS.

Further work beyond this thesis could also consider the role of exports and imports in IO analysis. Currently only the emissions embodied in UK production are considered because UK targets are calculated on this basis. However, further analysis should consider consumer responsibility. In the consumption accounting approach, our exports are consumed in other nations and are therefore not to be counted on the UK's carbon account. However, the carbon embodied in UK imports, which may be produced with different emissions intensities than in the UK, should be counted (Helm *et al*, 2007).

Chapter 4

Disaggregation of the UK electricity sector

1. MOTIVATION FOR DISAGGREGATION

One crucial sector in relation to GHG and CO_2 emissions is, of course, the production and distribution of electricity. The Input-Output analysis of the UK in Chapter 3 has highlighted the significance of the electricity sector in terms of its multiplier impact on UK economic output, and also on emissions in the UK, both directly and through its interdependencies with other industries. Given this sector's role in generating significant amounts of CO_2 emissions, a detailed analysis is necessary if the appropriate policy choices are to be made to limit its emissions. In particular; emissions' intensities vary radically across technologies. Therefore the separate identification of low-carbon generating technologies, such as nuclear and wind, against high-carbon generating technologies, such as coal and gas, is essential given that UK policy wishes to reduce emissions and stimulate new renewable technologies.

Since IO tables are built around the Standard Industrial Classification (SIC) system and since electricity is considered as one unified sector (Sector 40.1 in SIC 2003) within the classification, officially published IO tables cannot distinguish between generation, transmission, distribution and supply of electricity or disaggregate generating technologies.

If IO and CGE models are to be used to analyse UK climate change and renewables policy, it is therefore necessary to disaggregate the sales and purchases of the electricity sector into the heterogeneous generating technologies. The Environmental Accounts do provide the emissions figures for production of electricity by coal, gas, nuclear, oil and other technologies, which could facilitate possible attribution in an IO model.

It is necessary to attempt to disaggregate the UK electricity sector into its various components for at least two reasons. Firstly, in order to understand the extent to which certain technologies are responsible for output and emissions. Secondly, in order to identify how the substitution between electricity technology types may affect output and emissions in the UK economy. I therefore appropriately disaggregate the UKIO table for 2004 that was used in the previous analysis on the EU ETS in Chapter 3.

Section 2 gives a brief overview of previous work and literature regarding disaggregation of electricity sectors in other input-output databases. Section 3 provides an overview of how the UK electricity sector operates, what energy policies apply to the sector as well as a description of generation by each technology. Section 4 details my methodology for disaggregating the electricity sector in the UKIO for 2004. Section 5 gives the results of the IO analysis with the newly disaggregated electricity sector. Section 6 provides conclusions and extensions of this work.

2. LITERATURE REVIEW

The motivation and methodology for undertaking the disaggregation of electricity is informed by a small previous literature on this subject from various sources. The first attempt to disaggregate the electricity sector at the UK level was by Gay and Proops (1993). They use the IO framework to attach fuels (coal, oil and gas) to 38 industrial sectors in 1984, from which CO_2 intensities were calculated, and examine the production of CO_2 emissions in the UK.[82] One important distinction they make, regarding the way fossil fuels are used, is between 'direct consumption demand' and 'indirect consumption demand'. Direct consumption demand details the emissions

[82] They calculated a 3 x 38 matrix **C** which shows primary fuel use per unit of total output. They also had a 3 x 38 **P** matrix containing fuel use per unit final demand. They also calculated a vector of CO_2 emissions per unit of fuel burnt with assumptions made on how much CO_2 is generated when a solid, liquid or gas fuel is burnt.

caused in actual final demand consumption, for instance emissions from petrol used in household transport. The indirect consumption demand can be split into two distinct components of ‘direct production demand’ and ‘indirect production demand’. Direct production demand details any emissions produced directly in making goods or services that are bought by households such as the combustion of coal in electricity generation to manufacture a motor vehicle. The indirect production demand is where there are emissions from inputs into the direct good such as glass to go in a motor vehicle and all subsequent multiplier effects. Together these consist of all emissions produced within the economy attributable to final demand. Also, they note the importance of the electricity sector and therefore disaggregate that sector into three sub-sectors: fossil-fuel generation, other electricity generation and electricity distribution. They assumed that all output from the two generating sectors was sold directly to distribution and that distribution had no other intermediate inputs. Also, fuel inputs were attributed to fossil-fuel generation and all other inputs were split between the two generating sectors on the basis of their share of output. Their results give CO_2 intensities per unit of total output and per unit of final demand. They find that the three most CO_2 intensive sectors are coal mining, fossil electricity generation and electricity distribution, respectively. This is calculated by summing the direct consumption demand, direct production demand and indirect CO_2 intensities of the production demand elements.

Cruz (2002) considers the energy-economy-environment interactions in Portugal caused by emissions from the use of fossil fuels. This approach uses an IO table of 36 industrial sectors from 1992 and applies the same assumptions as Gay and Proops (1993) concerning electricity disaggregation. Electricity is split into three sub-sectors; fossil fuel generation, non-fossil fuel generation and distribution, and all generation is sold to the distribution sector. In total this gives them 38 sectors. However, Cruz also considers consumer responsibility by differentiating between Portuguese ‘responsibility’ for CO_2 emissions against CO_2 emissions produced by the Portuguese economy. This essentially switches from a production-orientated to a consumption-orientated measure of emissions and is achieved by treating emissions from imports and exports as the responsibility of the region they are consumed in.

For simplicity, energy and CO_2 intensity of imports are considered to be the same as those for the corresponding sectors in the domestic economy. The analysis shows that net Portuguese imports increase the overall emissions attributed to Portugal.

Allan *et al* (2007a) are concerned with electricity generation in Scotland and its effect on output of the Scottish economy. They use a mostly bottom-up methodology to disaggregate the Scottish electricity sector into eight generating technologies and a non-generation sector for an IO table in the year 2000. They use some micro-level survey data from the small number of large Scottish electricity generators reinforced by information from secondary sources. This disaggregated IO table is then used to calculate Type 1 and Type 2 output multipliers for each of the sixteen economic sectors they identify in Scotland. While initial results without disaggregation showed electricity as having the largest multiplier effects, their disaggregated results show that there is considerable heterogeneity between electricity generating technologies in terms of their effect on output. In particular they find that some low-carbon technologies, such as wind and nuclear, are highly import intensive and therefore do not contribute significantly towards Scottish output. They conclude that planned declines in coal and nuclear generating capacity will affect the economy differently. A £10m reduction in coal generation would result in a £20.5m loss to aggregate output but the same reduction in nuclear would result in a £12.5m reduction.

Similarly, some basic survey work was undertaken by Jones *et al* (2010) in which 88 economic sectors were distinguished in a domestic use table created by the authors for Wales in 2007. In particular they disaggregate electricity so there is an electricity distribution and supply sector as well as sectors for electricity generation by coal, gas, nuclear, as well as a sector for hydro and one for ‘other’ renewables. However, this table does not distinguish between these other renewable technologies. One paper which does distinguish between more technologies is Wiedmann *et al* (2011). They attempt to combine top-down and bottom-up approaches in detailing the UK electricity sector for a 2004 UK IO and use it to specifically analyse the wind power sector from an engineering viewpoint.[83] Their analysis has two regions, UK and ROW, and they have disaggregated these 224 economic sectors with nine different electricity generating sectors. They use data from the Centre for Sustainability Accounting (CenSA) specifically for wind power in the UK during 2004.

3. UK ELECTRICITY SECTOR AND ENERGY POLICY

3.1 Description of UK electricity sector

The UK meets a considerable amount of its energy needs through the production of electricity and this electricity is generated through various means which are shown in Table 4.1. The majority of UK generation is currently thermal and requires the burning of fossil fuels. In the UK the largest amount of electricity generated comes from gas-fired power stations and the second largest is from coal. These two technologies combined account for over two thirds of all electricity generated in the UK in 2004. This was not always the case. Helm (2007a) notes three supply-side trends that help explain the change in the UK: the ageing of assets and infrastructure (which reduced excess capacity); changes in technology choice towards cheaper energy; and concentration of oil supplies in the Middle East.

Many coal and nuclear power stations have been around for several decades and many are supposed to close in the near future although some have had their life extended in order to prolong generation. Until the 1980s the British coal industry supplied most of the UK's electricity needs but once this industry went into decline, partially through the policy choices of the UK Government at the time, no new coal stations were built. There was then a switch to gas-fired power stations which became the more prevalent new generation type in the 1990s. Gas-fired generation became the new technology of choice. Gas fired power stations are cheaper to build than coal plants, though the price of gas, as an input, tends to be more variable than

[83] A more general literature survey of energy and GHG modelling in IO models can be found in Mukhopadhyay and Chakraborty (2007)

the price of coal. In terms of emissions-intensity, gas power generation is less CO_2-intensive than coal generation.

The concentration of oil supplies in politically unstable regions of the world has also been a consideration for the UK Government and many other oil dependent Western nations. The 2011 conflict in Libya, a major oil producing nation, saw oil prices raise substantially as markets responded to increased risk and uncertainty. Also, Russia is a considerable supplier of gas to many European countries, so that energy security may be dependent upon political relations with Russia. There has therefore been a shift in attitude by Western nations towards less dependence upon oil and gas imports in an effort to enhance security of supply.

There are also low-carbon intensive generating technologies which have been present in the UK for several decades, such as hydro and nuclear power. Both of these technologies can provide stable generation of electricity. However, hydro has the problem that it must be built in particular locations and so has a limited scope for expansion.[84] It therefore only accounts for just over 1% of the UK's electricity supply. Nuclear has often gone in and out of favour with governments depending on changing knowledge, public opinion and world events. Although it can often be cost-competitive with coal and even gas generation, there are concerns over the safety of nuclear power which have limited its political feasibility in the UK. The share of nuclear in the generation of electricity in the UK has declined from around 23% in 2000 to only 13% in 2008 (DECC, 2010b). This reduction in the share of generation is partly due to decreased nuclear capacity after 2005 while the capacity of gas and renewable generation has increased. Also, nuclear generation increased from 52,846 GWh in 2008 to 69,098 GWh in 2009, while total electricity generation decreased between 2008 and 2009, which suggests that 2008 may have been an outlier for nuclear generation.

There are currently plans for new nuclear capacity to be built in the UK. However, events in Japan during 2011 concerning the Fukushima nuclear plant have again put

[84] Many Scandinavian countries use considerable amounts of hydro power in their electricity generation but in years when rainfall is limited, they have to import most of their electricity.

the future of nuclear power back on the political agenda in the UK and Europe. Although the Interim report from the Office of Nuclear Regulation in the UK in May 2011 states that they see no reason to curtail nuclear power in the UK. It appears that with nuclear power it requires a long-term commitment and investment but is seriously affected by "short-run" considerations.

Newer low-carbon generating technologies have expanded in the UK over the last decade, mostly in the form of onshore wind power, but also with biomass, offshore wind and the imminent deployment of marine energy. These technologies have been supported by subsidies such as the Renewables Obligation (RO) which require suppliers to purchase an increasing percentage of their electricity from renewables. Also, overall there are benefits to having a diverse portfolio of electricity production in order to provide security of supply (Awerbuch, 2006; Allan *et al*, 2010b). Table 4.1 shows the amount of electricity generated by technology for the years 2004 and 2008. The total electricity produced reduced year on year from 2006 to 2010 and electricity produced in 2008 and 2009 were particularly low due to reduced demand during the recession.

Table 4.1: UK electricity generation by technology and share in 2004 and 2008

Generation Technology	Total electricity generated (GWh) 2004	Share of total electricity generated	Total electricity generated (GWh) 2008	Share of total electricity generated
Coal	131,788	33.4%	125,376	32.2%
Gas	157,064	39.8%	176,215	45.3%
Oil power	4,644	1.2%	5,743	1.5%
Nuclear	79,999	20.3%	52,486	13.5%
Hydro	4,844	1.2%	5,168	1.3%
Pumped storage Hydro	2,649	0.7%	4,089	1.1%
Biomass	7,940	2.0%	10,335	2.7%
Wind onshore	1,736	0.4%	5,792	1.5%
Wind offshore	199	0.1%	1,305	0.3%
Other	3,062	0.8%	2,293	0.6%
Marine/geothermal/solar	236	0.1%	236	0.1%
Total	394,161	100.0%	389,038	100.0%

Source: DECC (2010b) – Digest of UK Energy statistics (DUKES)

Electricity generation from renewables has been growing year on year. In 2004 renewables provided 3.7% of total UK electricity generation and this has increased to 6.7% in 2009. Most of this increase has come through onshore wind which is now the second largest renewable in terms of output after increasing over 300% between 2004 and 2008. However, the uptake of renewables has been slightly slowed by the planning process and infrastructure because networks were not designed with peripheral renewable sources of energy in mind. It is also the case that renewables are limited in the same sense as hydro because they are a natural resource. There are only a certain number of specific areas which are efficient to operate wind turbines and once these have been used it will be difficult to expand renewable capacity unless through increased efficiency.

Given that electricity is a non-storable good, there is a need for supply to match demand instantaneously.[85] This requires a mix of the various generating capacity available at any one time. Balancing demand and supply is complex and often depends on the circumstances at that particular time. Generally there are ‘base-load’ power plants which normally provide the basic amount of supply at all times. These plants are usually coal and nuclear. Any fluctuations in demand are met by so-called peaking generators who provide the extra electricity in times where demand increases. This tends to be gas and oil generation, although these can also provide base-load. Given their intermittency, renewables cannot be relied upon to provide a stable base-load but also they can’t be easily switched on to meet extra demand. The ‘base-load’ plants tend to have relatively high fixed costs but a flat variable cost curve while the peaking plants tends to have lower fixed costs but a relatively steeper variable cost curve (Green, 2007). Short-run prices of wholesale electricity tend to be determined by the marginal plants because these technologies generally meet the fluctuations in demand in the UK. These are often the fossil-fuel generators like Combined Cycle Gas Turbine (CCGT) stations which are able to provide a reliable supply at short notice

[85] Technologies are being developed that allow for storage of electricity but currently these are still in R&D stage.

Once electricity is produced by generators, it is then purchased by retailers (suppliers) in the wholesale market. These retailers then sell the electricity on to end users, which will either be households or business in the various economic sectors, through the retail market. However, electricity networks are required in order to transmit the electricity from generators to consumers and these networks, owned by individual companies, are natural monopolies and so must be regulated. In the UK the regulator is Ofgem who protects consumer's interests and regulate the network companies through five-year price control periods. It is important as well to distinguish between transmission and distribution networks. Generators feed into the transmission network which carries electricity throughout the UK using high voltage power lines which often stretch over large distances. Then these transmission lines feed-in to the smaller, low-voltage distribution networks which supply electricity to the local area. There is a network operator which must control the supply of electricity through the power lines in order to make sure demand is met in a timely fashion. These networks, however, were historically designed for the older power plants and so do not easily meet the needs of transporting the electricity generated by many renewable sources which are often in peripheral locations. This is especially true for offshore wind and marine. Therefore upgrades and technological advances are necessary to the networks if renewables are to become a larger portion of electricity generation in the UK.

The electricity market was privatised in the UK in 1990. Then the electricity market was restructured in 2001 with the New Electricity Trading Arrangements (NETA), which was then extended with the British Electricity Transmission and Trading Arrangements (BETTA) in 2005. A detailed analysis of electricity pricing is beyond the scope of this thesis. The buying and selling, and therefore pricing, of electricity is achieved in various ways through the BETTA arrangements. There is a spot market for electricity which can often be volatile as well as forward and futures markets where contracts are drawn up years in advance. Plans for electricity market reforms have been laid out by DECC in their White Paper (DECC, 2011a). They see reform as necessary in order to provide security of supply because about a quarter of capacity is due to retire while demand is likely to rise. Also, reform is required to decarbonise the electricity sector in order to meet the carbon budgets. In particular the four main reforms will be: firstly, a carbon price-floor in order to reduce uncertainty. This will mean that the price of carbon in the UK cannot fall below a certain level. Secondly, changes to feed-in tariffs which incorporate long-term contracts. Thirdly, the introduction of capacity payments to ensure supply meets demand. Finally, emissions standards for new fossil fuel generators which will set the limit they can emit. This is to be 450g CO_2/kWh.

3.2 UK Electricity Sector Policy

Why is electricity generated by a variety of technologies and not just one and what will determine the composition of generation? The answer to this question relates to overall government energy policy and also the interests of the energy companies involved. UKERC (2007) explain the reasons why a government would want to intervene in the liberalised electricity markets and this will be to address some market failure, to address equity issues or to improve security of supply. The UK Government has the following energy policy goals: to reduce emissions; to maintain the reliability of energy supplies; to promote competitive markets in the UK and beyond; to help raise the rate of sustainable economic growth and improve our productivity; and to ensure that every home is adequately and affordably heated (DTI, 2007).

If the only goal of energy policy was “affordability” then Government policy would be designed to promote least cost technologies, which would not require substantial financial support. However, other goals have become more prominent in recent years, such as “reducing harmful emissions” and “security of supply”. These goals generally benefit from a variety of different technologies being employed in the production of energy. In fact they are essential in order for the goals to be achieved. New low-carbon technologies are required in order to reduce emissions by replacing fossil fuel generation and a variety of technologies will strengthen UK electricity supply security by lowering dependence on imported fuels. However, fossil fuel generation may still be necessary as back-up for intermittent renewables and would be effective in reducing emissions if combined with CCS. Therefore diversity of electricity generated is a key factor in UK energy policy. UKERC (2007) discusses at length the reasons why considering risk is essential for investment in electricity generation; it is limiting only to consider cost when designing policy.

Individual energy companies will also have an interest in not relying solely on one generating technology in the production of electricity. Many of the energy companies that generate electricity are also suppliers and by diversifying into different generation types they can hedge against possible fluctuations in the price they pay for electricity as a supplier. Modern theories of imperfect competition also link productivity to diversity in inputs (Dixit and Stiglitz, 1977; Krugman and Venables, 1995; Venables, 1996). How they diversify will be determined through liberalised markets but it will also be affected by policy. Government energy policy will influence what generating technology companies invest in when adding new capacity. These investors, who realise that these plants will be operational for several decades, will invest in new technologies only where there are assurances that the technology will be supported over a lengthy time period.

There are various policy instruments in the UK which are aimed at affecting the composition of generation within the electricity sector in order to achieve energy policy goals. The most important are the EU ETS (which we have already discussed at length in Chapter 3), the Renewables Obligation and the Feed-in Tariff Scheme (FiTS). Whereas the EU ETS is attempting to reduce emissions in a non-technology specific way, the other two schemes are specifically attempting to increase the penetration of renewables in the electricity market over the coming decades. The most prominent of these has been the Renewables Obligation (RO).

The Renewables Obligation was introduced in England and Wales in 2002 and has applied to Scotland since 2004 and Northern Ireland since 2005. It requires electricity suppliers to source a proportion of their electricity from eligible renewable generation. This proportion increases over time; it was 4.9 per cent in 2004-05 and 9.1 per cent in 2008-09. Suppliers meet their required obligation in one of two ways.

The first is to surrender Renewables Obligation Certificates (ROCs) which are purchased either from generators or on open-market trading. The second is by paying the buy-out price, which is a standard price set that is required to be paid by suppliers for every MWh of their obligation not met by presenting ROCs. The supplier can also meet the obligation by using a combination of both ROCs and buy-out. The buy-out paid by suppliers is redistributed to those suppliers who did present ROCs in proportion to the amount of their obligation they met through ROCs. Generators of renewable electricity therefore benefit both from selling electricity to the network at the market price and selling ROCs on the certificate market.

Table 4.2: Renewable Obligation Certificates issued in 2004 by technology

Technology Type	ROCs total MWh	Perecntage share
ACT	9,903	0.09%
Biomass	829,924	7.6%
Co-firing	2,116,599	19.5%
Hydro < 20 MW DNC	1,959,130	18.0%
Landfill gas	3,656,569	33.6%
Micro hydro	46,804	0.43%
Off-shore wind	277,351	2.55%
On-shore wind	1,725,140	15.9%
PV	28	0.00%
Sewage gas	249,481	2.29%
Total	10,870,929	100.00%

Source: Ofgem (2006)

The renewable sources which are able to receive ROCs are decided by the UK and devolved Governments and currently these are onshore and offshore wind, biomass, co-firing, landfill gas, sewage gas, hydro power stations (either under a certain size or new built large stations) and marine. Table 4.2 shows the ROCs issued in the UK for the base year of 2004. Generally governments do not wish to "pick winners" i.e. fund one technology, which is inconsistent with the general emphasis on competitiveness. This was why the ROC scheme was initially "technology blind" with all technologies given the same support. Initially ROCs were issued on the basis of one ROC per MWh of renewable electricity generated. However, it was soon apparent that although this banding stimulated the development of renewables, it was not achieving the desired effect of diversity. This was because it only incentivised investment in the technologies closest to market, mostly onshore wind. Therefore in April 2009 banding of ROCs was introduced so that different renewable technologies receive different amounts of ROCs for the electricity that they generate. Technologies such as marine and offshore-wind receive two ROCs per MWh generated whereas onshore wind receives one ROC per MWh and landfill gas gets only one-quarter of a ROC per MWh of electricity generated. This is an attempt to level the playing field in order to help bring down the costs of those technologies which are further from market deployment while simultaneously lowering the support for technologies which were perhaps becoming over-subsidised.[86]

In essence the Renewables Obligation has created a quantity system where permits are traded and the price of these permits varies over time whereas FiTS is a price scheme where a predetermined price is paid to generators per kWh of renewable generation provided to the network.[87] Some feel that price variability of ROCs does not help investors in renewables because it creates uncertainty in their revenue stream and investors prefer feed-in tariffs because they provide a more stable and certain income stream for firms therefore lowering the cost of potential risk. In the UK ROCs apply to large-scale generation while FiTS only applies to small-scale generation lower than 5MW of installed capacity. However, in many other EU countries a feed-in tariff has been used as the main subsidy for renewables. Sjim (2002) discusses the performances of feed-in tariffs in Germany, Denmark and Spain and evaluates them based upon investment certainty, effectiveness, efficiency, market compatibility and administrative demands. He finds that although there are certain issues with cost effectiveness and competition, the feed-in tariffs have been effective in achieving the necessary effects on promoting renewables over the short term but that it may not be sustainable to continue the subsidies over the long-term.

[86] For an overview of the experiences of the RO scheme in the UK see Woodman and Mitchell (2011).
[87] The feed-in tariff can either be a percentage (normally of the electricity price) or fixed and the premium level may also be differentiated between technologies. See Menanteau *et al* (2003) for a theoretical comparison of policies for promoting renewables.

More recently Mitchell *et al* (2006) as well as Butler and Neuhoff (2008) compare the effectiveness of the RO in England with the German feed-in tariff and find that the feed-in tariff has been more effective in deploying renewables, in particular onshore wind, and reducing consumer costs. The RO scheme in the UK will be replaced in 2017 by the Feed-in Tariff with Contracts for Difference (CfD) scheme which was briefly discussed in Chapter 2.

4. DATABASE DISAGGREGATION AND CONSTRUCTION

Due to a lack of available micro-level UK electricity data, a top-down approach is used to disaggregate the electricity sector. All entries are constrained to sum to the original UKIO table entries for the electricity sector as a whole. Firstly, I follow the methodology used by Proops and Gay (1993) and Wiedmann *et al* (2011) by distinguishing between the production of electricity and its distribution, trade and supply. However, many of the companies that are involved in the electricity sector operate in several stages of the process from generation to supply. For example, many utility companies generate electricity using a number of technologies which access a range of resources. These utilities also provide consumers with both electricity and gas and sometimes own the electricity networks. In this case, it is therefore difficult to use company-level data for this kind of disaggregation. Whilst Ofgem requires the six largest energy companies to report their annual accounts and split them between electricity generation and trade this does not provide enough detail for appropriate disaggregation.

Some basic information is available from the Annual Business Survey (ONS, 2010c) which gives turnover, purchases and gross value added for SIC 40.1 which describes the electricity sector. This information is separated out further for electricity production (SIC 40.11), transmissions (SIC 40.12) and distribution and trade (SIC 40.13). This allows us to split the total electricity sector into distinct sub-sectors. Given that from an environmental viewpoint it is the generation of electricity that concerns us most, it is simplest first to split the aggregate sector into just two sub-sectors: generation and supply. Generation will consist of all production and so represent SIC 40.11. Electricity supply is the combined sectors 40.12 and 40.13. All output from the generation sector must be sold directly to the supply sector which is then able to sell it on to other industries or to final demand (Proops and Gay, 1993). Therefore there are no sales to final demand for electricity generation and no sales from electricity generation to any other sector except supply of electricity. All original sales from electricity to all other industries are now attached to the electricity supply sector.

Table 4.3: Turnover, GVA and purchases for SIC 40.1 (in £millions for 2004)

Year 2004	SIC	Total Turnover	Approximate gross value added at basic prices	Total purchases of goods, materials and services
Production of electricity	40.11	8,949	3,078	5,889
Transmission of electricity	40.12	4,899	2,671	2,226
Distribution and trade in electricity	40.13	22,367	6,803	16,155
Production and distribution of electricity	40.1	**36,215**	**12,552**	**24,269**

Source: ONS (2010c) Annual Business Inquiry (ABI)

Table 4.3 shows that production of electricity accounted for roughly 25% of total turnover of the entire electricity sector in 2004. Therefore, in the IO accounts, I assume that total sales from generation are 25% of the total demand for products of electricity (the sum of intermediate and final demand), which is equal to total output. It should be noted that the IO table and ABI figures do not match. Total turnover in 2004 for electricity is given as £36125 million in the ABI as opposed to the IO table total demand for electricity of £33197 million, which is 8% lower than the ABI figure. However, I assume that the ABI data accurately capture the appropriate share of electricity production as a share of total electricity, then taking 25% of total demand (according to the IO table) gave a figure of £8299 million and this represents total sales from generation to supply of electricity. Another method would be to consider all inter-industry transactions as sales from generation to supply. In the original IO accounts inter-industry electricity purchases are £9581.8 million. This is only slightly larger than the figure obtained using the ABI data by taking 25% of total turnover. It is likely that there will be transactions between distribution, trade and supply of electricity and so the remainder of electricity inter-sectoral purchases are considered to be sold from electricity supply to itself. This is the original £9581.1m less the 25% of total demand (£8299) giving electricity supply sales to itself of £1282.7 million.

Secondly, the electricity generation sector required to be disaggregated into the various generating technologies. However, there is a question of the level to which generation should be aggregated or disaggregated i.e. how many generating technologies to include. A simple disaggregation of the generation sector could split between renewables and non-renewables to allow for a basic distinction, or this could be implemented differently as 'low-carbon' versus 'carbon-intensive' technologies. This is an important distinction because nuclear generation would be considered "low-carbon" but not "renewable". Alternatively, the disaggregation of generation could match the technologies listed in the Environmental Accounts, since emissions data are available for these, or be disaggregated even further to detail the various renewable sources of electricity production used in the UK, however small they are.

A decision on this disaggregation must be made based upon data sources available and also upon the policy questions that we want to tackle. Given that the analysis concerns the role of individual technologies I wish to disaggregate as much as possible. This may allow tracking of technologies over time as updated information and IO tables become available in the coming years. Having already disaggregated the IO table to take account of the EU ETS policy instrument (in Chapter 3), it would now seem appropriate to attempt to identify important sectors for the other energy policy initiatives, notably ROCs and FiTS. It is therefore appropriate to not only identify renewable generation, since these policies are a subsidy for them, but to also distinguish among renewables since these policies are now designed to provide different subsidies for different technologies such as the banding of ROCs. Although I do not attempt to model renewables subsidies in this thesis it is important to be aware that the extent of disaggregation of the electricity sector at this stage may make incorporating ROCs in future analysis easier to implement.

The disaggregation procedure is not, however, straightforward as no detailed data on electricity production for IO tables exist. I firstly consider how to disaggregate sales from generation into the various technologies and then turn to how purchases are disaggregated for each generating technology. For sales from the generation sector to the electricity supply sector, it may be possible simply to disaggregate on the basis of each technology's share of generation of UK electricity for 2004 (since the UKIO table is for 2004). This information is given in Table 4.1 above. Ideally, assumptions regarding inputs to each generating technology would then be based upon other data, where available, although any external data used would not necessarily be constrained to the row and column figures in original UKIO table for 2004.

The £8299 million of sales from electricity 'generation' to 'supply' has been apportioned to each generating technology based upon their percentage of total generation for 2004 (see Table 4.1). The disaggregation is therefore based on the quantity produced i.e. physical generation, not on the actual value of sales. This method implicitly assumes, unrealistically, that there is a uniform price of electricity produced by all generating technologies. Using this method we get an average price of electricity as 2.121 pence per kWh, when sold from generation to supply, in the IO table.[88] In practice the price of electricity sold by each generating technology to supplier will vary depending upon the cost of inputs, the time of day and changes in demand. Gas, oil and coal commodity prices as well as CO_2 permit prices will influence the price of electricity from these generating sources and renewables may require subsidies to make them cost-competitive. However, final consumers do not purchase electricity based upon its method of generation but directly from the supply sector. The average price in 2004 of electricity sold to the manufacturing industry was higher at 3.126 pence per kWh (DECC, 2010b, in DUKES Table 3.1.3). This

[88] Calculated by dividing £8299m sold from generation to supply by the total electricity generation in 2004 of 391214 GWh.

price varied between 2.666 p/kWh for extra large consumers and 4.634 p/kWh for small companies. This method, however, is concerned with sales from electricity generation to supply and not sales from supply to other economic sectors. Therefore this difference between prices likely reflects a mark-up on the price of electricity. However, given that generation only accounts for 25% of total electricity sector output in the ABI data then the mark-up on household consumers of electricity will be even higher again. The assumption that electricity is a homogenous good in the IO table, while in practice the price varies across sectors, will mean that the emissions associated with intermediate demand of some sectors will be greater than reported and others will be less.

In the IO table I have currently disaggregated the original "electricity" row into "Electricity supply" and eight generating sectors. These are "Nuclear", "Coal", "Gas and oil", "Hydro"[89], "Biomass", "Wind", "Marine" and "Other". I assume that all generation from each technology is sold on to the electricity supply sector. However, it is more difficult to disaggregate the column showing the inputs to electricity supply and generation into various sub-sectors, one for each technology (The way in which this is done will determine the nature and extent of backward linkages.) The difficulty is due to a lack of information available regarding the composition of purchases by individual electricity generators because of the fact already noted that electricity companies will often have several generation types and so purchases may not be separately distinguished by technology. Furthermore, this information may not be publicly available to protect business interests. The Digest of UK Energy Statistics (DUKES) provides a chapter on renewables in its yearly report but this mostly concerns supply and does not go to the level of detailed purchases. For all generating technologies I therefore required more information or engineering assumptions. In summary, to balance the IO table several assumptions are required regarding purchases by generating technologies given the lack of available data.

Most other IO analyses of this type (Gay and Proops, 1993; Cruz 2002) have separated all inputs based on their share of total output and this must make the results

[89] Currently the table is only natural flow hydro power and does not include pumped-storage hydro.

inaccurate, for instance, as renewables will not purchase fuel inputs. I therefore make several assumptions pertaining to inputs to generating technologies when disaggregating the original electricity sector. In the 29 sector IO table the main purchases by the original electricity sector are from: the electricity sector itself (£9581.8 million), 'Mining and quarrying' (£3968.4 million), 'Services' (£1266.5 million) and 'Gas, water and construction' (£1074 million). I considered these sectors in more detail by referring back to purchases figures from the 123 sector IO table and then made assumptions regarding their allocation.

As mentioned above intra-industry electricity purchases have been disaggregated into the various generating technologies, all of which are sold to supply, as well as a residual amount of £1282.7 sold from supply to itself. It is assumed that all of the original electricity purchases from the 'Mining of the coal, lignite and peat' sector in the 123 sector IO table are purchased by the 'Coal electricity generation' sector in the 29 sector table, amounting to £788.3 million. Also, it is assumed that a quarter of all purchases by electricity from the 'Extraction of crude petroleum and natural gas' sector in the 123 industry IO table are attributed to the 'Gas and oil electricity generation' sector of electricity in the 29 sector model, with the remaining 75% being sold to "Electricity supply". This assumption is consistent with the ABI data that states that 25% of electricity sector inputs are purchased by the generation sector. I assume that the entirety of these purchases is made by the 'Gas and oil electricity generation' sector and no other generating types.

There are considerable purchases by the electricity sector from the 'Gas distribution' sector in the original 123 sector IO table. Using roughly similar disaggregation of purchases as appears in Allan *et al* (2007a) it is assumed that 50% of these purchases are sold directly to "Gas and oil electricity generation", with another 10% sold to "Coal electricity generation" and the remainder going to "Electricity supply". 90% of the original 'Water distribution' sector is assumed to be sold to "electricity supply" with the other 10% going to "nuclear generation". Again this is similar to Allan *et al* (2007a).

The "Construction" sector purchases account for all construction costs that are not capital purchases. Essentially this will be repair and maintenance costs as capital purchases should be included in Gross Fixed Capital Formation (GFCF) in final demand. One limitation of the modelling used throughout this thesis is that it only considers the operational aspects of the electricity generation technologies and does not capture the development and constructional aspects which will impact upon employment and emissions during the life-cycle of electricity generating technologies. However, to separate the purchases from the 'construction' sector made by the electricity sector, which is £271.8 million, it seems inappropriate to use Allan *et al* (2007a) as a basis. For Scotland in 2000 over 50% of electricity sector construction was attributed to hydro generation with nuclear and coal making up a further 20% each and electricity supply and marine purchasing 2% and 0.04% respectively. All other renewables appear to purchase nothing. This seems an unlikely scenario for the UK in 2004, especially with the growth in renewables and the reasonably substantial maintenance cost of these new technologies like wind.[90] In the table created by Jones *et al* (2010) for Wales, all renewables together are responsible for around 69% of electricity sector purchases from construction in 2007. Therefore I assume a lower proportion (30%) is sold to renewable generating technologies in the UK to reflect the difference in renewables intensity between Wales and the UK as a whole. This 30% is split between each technology based on their share of renewable generation in 2004. For the rest of "Construction" the remainder is apportioned to "Gas", "Coal" and "Nuclear" generation 10%, 5% and 5% respectively given their capital-intensity and consistency with the Welsh table and the rest goes to "Electricity supply" sector.

Apart from the largest purchasing sectors detailed in the paragraph above, I made assumptions regarding some other purchases by generating technologies. For simplicity the assumption is that all of the original purchases by electricity from the fuel-intensive 'Coke, refined petroleum and nuclear fuel' sector are attributed to inputs to "nuclear electricity generation". "Agriculture" sales to the original electricity sector are apportioned as three quarters sold to "Electricity supply" while

[90] Purchases from the construction sector by the various electricity generation technologies should not include new-build capital.

the remaining quarter is sold to “Coal generation”. This is based upon the IO table from Allan *et al* (2007a). In future work there may be a case for having biomass generation purchase some of its inputs from the agriculture sector. For purchases for the wind sector CenSA provided data which details purchases by the wind power sector in the UK during 2004 for 224 sectors, including domestic and imported purchases. These data are for all wind generation and thus are not split between onshore or offshore wind. We wish to differentiate between onshore and offshore technologies if possible, given that they now receive different ROC bands. Also, when the CenSA data was aggregated to match the 29 sectors in the IO table it did not seem compatible with the IO table. In particular, there were some purchases figures for the wind sector that were higher than the entire electricity sector purchases in the original UKIO. Purchases by the wind sector from “Iron and Steel” were £7.35m in the CenSA data but purchases from the original electricity sector were only £3.2m. It is likely that this data included new-build capital costs. Therefore, given these inconsistencies, this data was not used in the disaggregation as it would contradict the original IO table.

The remainder of the purchases by generating technologies are apportioned in the following way. First, I allocate 25% of total electricity sector purchases from each sector of the economy to the generating sector as a whole. Second, this amount is multiplied by each individual generation technology’s percentage share of total generation.[91] On top of this, various small adjustments were required so that the IO table balanced. The gross operating surplus (other value added) entry was used to do this. There are also some small adjustments where purchases from gas electricity generation sector are moved to either nuclear or coal generation in order to get the gas generation sector to balance.

Value added must also be disaggregated across the generating technologies requiring various assumptions to be made. Firstly imports are disaggregated. Imports from the hydro, biomass and landfill generation sectors were set to zero since the nature of

[91] See Table 1 for split of electricity purchases in the ABI

these technologies make it highly unlikely that any would use imported inputs.[92] Hydro has been used in the UK for a considerable time and inputs can be sourced locally while biomass and landfill will also use local inputs. The rest of imports were apportioned 75% to the supply sector and 25% to generation, further split to each technology based on their share of generation. The remainder of what imports would have been assigned to hydro and biomass were attached to the electricity supply sector.

Data from the Annual Business Inquiry (ONS, 2010c) indicates that in 2004 around 30% of total employment costs in SIC 40.1 were attributable to production of electricity. Therefore 30% of total employment costs in the original IO table are allocated to the generation sector as a whole. The ABI states that in 2004 there were around 20,000 people employed in the production of electricity at a cost of around £717 million. The average wage in the generation sector is therefore around £35,850 per annum. This is consistent with Allan *et al* (2007a) who derived an average wage of £42,000 for nuclear, coal and gas facilities in Scotland while assuming a lower annual wage of £34,000 for workers in hydro, wind and other renewables except marine. It was then possible to disaggregate the 30% of employment costs to each technology based on their share of generation but this overestimated the number of jobs in total generation. Instead I calculate the number of jobs in each generating sector using data on jobs per GWh from Allan *et al* (2007a). This slightly underestimates the number of jobs but by scaling these results up in line with overall generation being 30% of total employee compensation, this then gives estimated figures for the number of jobs and payment in wages to employees for each generating sector (see Appendix E for more information on these calculations).

In terms of 'net taxes of products and production', these are split simply based upon share of generation. However, in future research, it may be necessary to attempt to incorporate government subsidies for electricity generation, such as ROCs for renewables, in the value added row which details taxes paid by each industry. Originally all these transactions would be detailed in the one entry in the IO table but

[92] However, there are proposals for major new biomass plants in Scotland that will import fuel so that this assumption may need to be monitored and revisited in future.

now that we are disaggregating the electricity sector it would seem appropriate to attempt to incorporate the RO as a policy instrument. However, although some initial work was done on this, further research beyond this thesis is required to ascertain the correct way to identify the subsidies within the IO table.

The ‘gross operating surplus’ element within value added acts as a residual which is used to balance the IO table. I keep the split of the EU ETS traded and non-traded sectors detailed in the previous chapter with a few aggregations of service sectors and also agriculture has been combined with forestry and fishing. The matrix of the disaggregated electricity sector in the IO table is provided as Table E3 in Appendix E.

This is a first attempt at modelling these often nascent sectors. Given that many of the necessary data are not available, any analysis must be considered as illustrative and must be updated when it is possible to acquire richer data on the sales and purchases of generating technologies. Greater pressure for more data on this key sector should help generate more accurate information in the future. This is hopefully a first step towards having a richer understanding of the UK electricity sector for modelling purposes.

5. RESULTS

Using the UKIO database with the now disaggregated electricity sector, output, employment-output and CO2-output multipliers are calculated for each sector of the economy. These multiplier results and their respective rankings are shown in Table 4.4 for output, Table 4.5 for employment and Table 4.6 for carbon dioxide emissions. These results, with nine generating technologies and a supply sector, were then compared to the original multipliers calculated when modelling the EU ETS in Chapter 3, where there was only one single electricity sector encompassing all generation and supply activity. The electricity supply sector is sector 13 and the electricity generation sectors are 14-22.

5.1 Output Multipliers and Employment-Output Multipliers

Table 4.4 shows that the largest Type 1 output multiplier is 2.37 in the 'Gas and oil' generation sector which has the largest output of all the electricity generating technologies. This suggests that for a £1 million increase in final demand for electricity generated by 'Gas and oil' there would be an overall increase of £2.37 million in the UK economy. This suggests strong backward linkages for this sector in the UK economy. The sector with the second largest multiplier is the 'Electricity supply' sector (2.29) which consists of all non-generation activity. The 'Electricity supply' sector, however, has a very similar cost structure (and therefore multiplier values) to the original electricity sector because of the way that the sector has been disaggregated, as described in Section 4.

Table 4.4: Type 1 and 2 output multipliers and ranking for 29 sectors including disaggregated electricity sector

sec No.	**Output multipliers** Sector	Type 1	Rank (1-29)	Type 2	Rank (1-29)
1	Mining and quarrying	1.52	29	2.17	28
2	Food and Drink	1.97	9	3.28	12
3	Textiles; wearing apprrel; leather products	1.77	19	3.23	14
4	Wood; Pulp and paper; Printing and publishing	1.76	21	3.17	17
5	Coke, refined petroleum products and nuclear fuel	1.95	10	2.78	25
6	Gases and dyes; Chemicals	1.95	11	3.09	21
7	Glass and glass products	1.79	16	3.28	13
8	Ceramic goods	1.64	24	3.29	10
9	Clay, cement, lime and plaster	1.78	18	3.10	20
10	Articles of concrete, plaster and cement;	1.88	12	3.32	7
11	Iron and Steel; non-ferrous metals	1.98	8	3.19	16
12	manf of Motor vehicles and other transport	1.84	13	3.12	19
13	Supply of electricity	2.29	2	3.12	18
14	Nuclear	1.52	28	2.07	29
15	Coal	1.82	15	2.54	27
16	Gas and Oil	2.37	1	3.31	8
17	Hydro	1.53	27	2.92	23
18	Biomass	2.05	7	4.17	1
19	Onshore Wind	2.22	3	3.61	4
20	Offshore Wind	2.22	5	3.88	3
21	Other generation	1.61	25	3.48	5
22	Solar/Marine	2.22	4	4.01	2
23	Agriculture, forestry and fishing	1.84	14	2.88	24
24	Other Manufacturing	1.79	17	3.20	15
25	Gas and water supply; Construction	2.07	6	3.28	11
26	Wholesale retail trade; Repair of vehicles; personal and household goods; Hotels and restaurants	1.76	22	3.30	9
27	Air Transport	1.66	23	2.76	26
28	Other Transport	1.77	20	3.33	6
29	Services	1.61	26	3.08	22
original	Production and distribution of electricity	2.300		3.042	

The third, fourth and fifth largest multipliers are for the ‘onshore wind’, ‘solar/marine generation’ and the ‘offshore wind’ sectors which are all around 2.22. The fact that they are similar is mostly due to the top-down method of disaggregation and limited available knowledge about the inputs to each technology. If accurate this result would show that newer low-carbon technologies may have significant benefits in terms of economic growth as well as emissions reductions. However, previous analyses have suggested small multiplier effects of renewable technologies (Allan *et al*, 2007a) because of substantial imported inputs instead of domestic inputs. Therefore they find a small local impact of technologies such as onshore wind. Also, this analysis for Scotland was undertaken before the ROC system was in place. It is interesting to note the larger results in my analysis which may partly be because the ROC subsidy changes the composition of purchases and therefore the multiplier effect. More accurate UK level data is needed on imports and domestic purchases by these low-carbon sectors to fully understand the extent that their inputs have on multiplier effects in the economy. While the multiplier effects of more established generating technologies appear to be as expected after disaggregation, highly capital-intensive, the renewable technologies results are somewhat surprising. Therefore the output multiplier results of this analysis for individual renewables should not be considered conclusive. However, the important distinction between fossil-fuel and low-carbon technologies has been made and can be improved upon in future work.

Although subsidies will not affect the output multiplier results, given the fixed technology assumption, the substantial subsidies from ROCs will allow the scale of the purchases in these sectors to occur. It is interesting to note that in many cases there is a considerable difference between the value of sales and the value of output (net of subsidies) for technologies. There are even instances, as with biomass, onshore wind, and offshore wind, where the subsidy amounts for the year actually exceed the value of sales. Without the large production subsidies, the level of gross output for these sectors would significantly different. This may also be the case for other sectors, such as ‘Agriculture’, where subsidies are received, but this will affect the output level to a lesser extent because the subsidy is small compared to the value of total output.[93] The incorporation of subsidies therefore increases output level of sectors which receive them and taxes will do the opposite. Further work beyond this thesis is required on identifying and incorporating renewables subsidies in the input-output database in order to fully understand the effects that these subsidies will have on the sectors in terms of a policy shock.[94]

Figure 4.1: Type 1 and Type 2 output multipliers

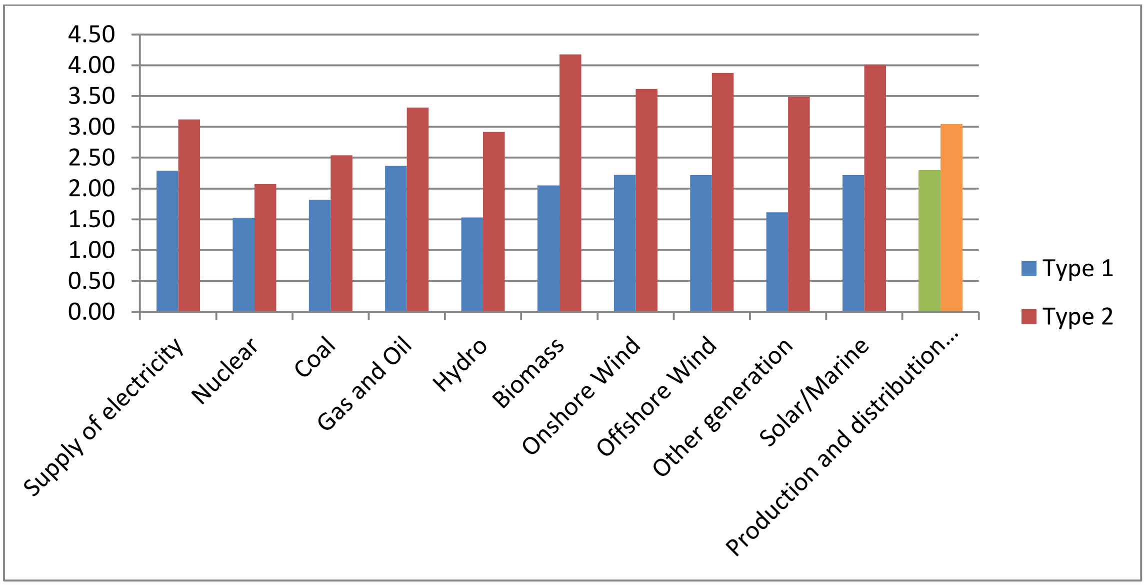


Figure 4.1 shows the Type 1 and Type 2 output multipliers for the electricity sector (in blue and red respectively) as well as the original electricity sector Type 1 and 2 (in green and orange respectively). The heterogeneity of output multipliers for generating technologies is striking from these results. While 'Gas and oil', 'Electricity supply', 'Solar/marine' and both types of wind power have the largest Type 1 output multipliers, many of the other generating technologies have particularly low output multipliers. In particular, 'Hydro' and 'Nuclear' power are ranked 27th and 28th respectively out of 29 sectors. This suggests that these technologies do not have particularly strong backward linkages within the UK

93 For instance, 'Agriculture' has a negative entry of £427 million in the 'net taxes on products and production' row of value added compared to gross output of £21134 million in the original 123 sector IO table.

94 Table E2 of Appendix E gives a breakdown of the costs of production for the disaggregated electricity sectors in the IO table. With further work on incorporating ROCs the proportion of taxes may well be significantly negative.

economy, probably due to the high capital intensity of these generating technologies. Also, important to note is that 'Nuclear' receives no subsidy and 'Hydro' receives considerably less subsidy than other renewable technologies.

When households are made endogenous to the model it is possible to calculate Type 2 output multipliers. Table 4.4 shows that the largest Type 2 output multiplier is for 'Biomass' at 4.17, which was ranked 7th of all the Type 1's. This is likely influenced by my assumption of jobs per MWh for the biomass technology which determine how much extra income is spent by households once they are endogenised within the model. The second largest is for the solar/marine generation sector at 4.01 although the size of this sector is particular small in the table. 'Onshore' and 'Offshore' wind generation as well as 'Other' generation also have large Type 2 multipliers. 'Gas and oil' electricity generation is only ranked 8th once households are endogenous, reflecting the fact that it is not a particularly labour-intensive sector. Also, 'Nuclear' is ranked lowest of all at 2.07 and 'Coal' generation is ranked 27th with a Type 2 output multiplier of 2.54. These generating technologies are particularly capital-intensive in this disaggregation and employ relatively small amounts of labour which may explain their low Type 2 multipliers. Again these Type 2 results will be dependent upon our employment assumptions for these technologies.

The original electricity sector's Type 1 output multiplier was 2.3 and it was the highest ranked of all economic sectors in the previous multiplier analysis, while the original Type 2 output multiplier for electricity was 3.04 and only ranked 15th of all sectors. The now disaggregated electricity sector effectively shows the decomposition of this multiplier and the substantial heterogeneity among generating technologies. It is clearly important for disaggregation to occur, from the perspective of impact effects on output.

Table 4.5: Employment-output multipliers for electricity sectors

employment-output multipliers			
No.	Sector	Type 1	Type 2
13	Electricity Supply	9	19
14	Generation - Nuclear	7	14
15	Generation - Coal	8	16
16	Generation -Gas + Oil	11	22
17	Generation - Hydro	13	29
18	Generation - Biomass	20	46
19	Generation - Wind	16	33
20	Generation - Wind Offshore	19	38
21	Generation - Other	17	39
22	Generation - Marine/solar	18	40

Table 4.5 gives Type 1 and 2 employment-output multipliers for the now disaggregated electricity sector. These show the number of jobs that would be created in the economy if final demand for electricity generation from a technology (or electricity supply) was to change by £1 million. Electricity supply has the lowest employment effect from changes to final demand and this is because 70% of employment in electricity sector is in transmission, distribution and trade. The other 30% is split between the generating technologies. Biomass has the largest employment-output multipliers suggesting that for an increase in final demand of £1 million of Biomass there would be an extra twenty jobs created in the economy. Where households are made endogenous this figure increases to forty-six jobs. This is closely followed by offshore wind, marine/solar, landfill gas and onshore wind. However, in our model none of the technologies sells straight to final demand and these employment effects will come through the electricity supply sector.

5.2 CO_2-output multipliers

A vector of CO_2-output coefficients for each economic sector was calculated using the Environmental Accounts (ONS, 2010a) which link CO_2 emissions to output for each individual sector. These are the same as in Chapter 3 except for the electricity sector and where some sectors have been aggregated. In ONS (2010a) CO_2 emissions are given for gas, oil, coal, nuclear and ‘other’ electricity production. Here, I assume that the ‘other’ emissions are attributed solely the electricity supply sector. Therefore the only disaggregated generation sectors in the new IO table which have emissions linked to output are “Gas and oil’, ‘Coal’, ‘Nuclear’ and ‘Electricity supply’. No other generating technologies produce emissions. However, it is likely that, in practice, some of the other generating technologies in the IO table are responsible for the CO_2 emissions through construction and maintenance. In this chapter GHG-output multipliers are not discussed at all as these are very similar to the CO_2-output multipliers across all generating technologies and also across all economic sectors except ‘Agriculture’ (which was discussed in Chapter 3). Although both Type 1 and 2 multipliers are given here, the emphasis should be focussed on the Type 1 multipliers as it seems unfair to consider the effect workers have on the environment, in Type 2, as they have to work somewhere. Both are given however for comparison.

Table 4.6: CO_2-Output multipliers (Tonnes of CO_2 generated to meet a £1million increase in sector final demand)

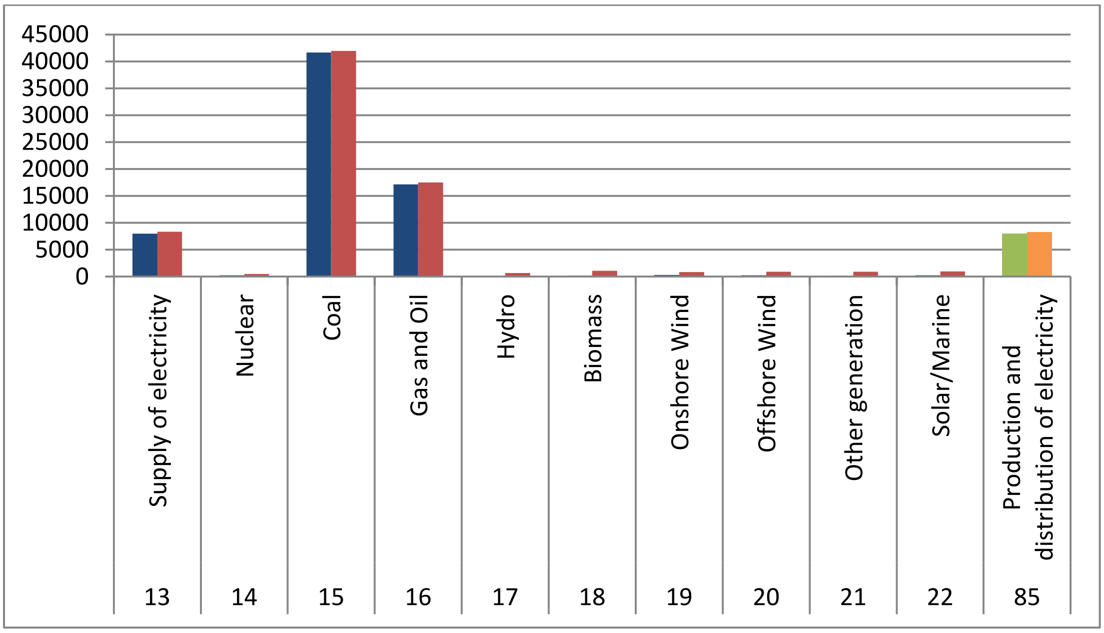
sec No.	CO2-Output multipliers Sector	Type 1	Rank (1-29)	Type 2	Rank (1-29)
1	Mining and quarrying	1002	10	1269	12
2	Food and Drink	439	16	981	19
3	Textiles; wearing apprrel; leather products	453	15	1057	15
4	Wood; Pulp and paper; Printing and publishing	415	18	998	16
5	Coke, refined petroleum products and nuclear fuel	1601	7	1945	7
6	Gases and dyes; Chemicals	1122	8	1594	9
7	Glass and glass products	1072	9	1687	8
8	Ceramic goods	602	13	1284	11
9	Clay, cement, lime and plaster	7717	4	8266	4
10	Articles of concrete, plaster and cement; cutting, shaping and finishing of stone; manufacture of other non-metallic products	847	11	1441	10
11	Iron and Steel; non-ferrous metals	2388	6	2890	6
12	manf of Motor vehicles and other transport	347	20	876	25
13	Supply of electricity	7995	3	8339	3
14	Nuclear	264	22	491	29
15	Coal	41617	1	41916	1
16	Gas and Oil	17138	2	17528	2
17	Hydro	103	29	678	28
18	Biomass	210	26	1090	14
19	Onshore Wind	294	21	870	26
20	Offshore Wind	246	25	932	21
21	Other generation	120	28	894	24
22	Solar/Marine	246	24	988	18
23	Agriculture, forestry and fishing	552	14	980	20
24	Other Manufacturing	413	19	994	17
25	Gas and water supply; Construction	428	17	930	22
26	Wholesale retail trade; Repair of vehicles; personal and household goods; Hotels and restaurants	262	23	901	23
27	Air Transport	2981	5	3439	5
28	Other Transport	614	12	1256	13
29	Services	162	27	771	27
Original IO table	Production and distribution of electricity	7993		8297	

Table 4.6 shows that the largest CO_2-output multiplier, for both Type 1 and Type 2 calculations, is for the "Coal generation electricity" sector. This Type 1 (Type 2) multiplier states that for a £1 million increase in final demand of coal generation there would be 41,617 (41,916) extra tonnes of CO_2 emitted in the UK. "Gas and oil generation" has the second largest CO_2-output multiplier of all 29 sectors with 17,138 (17528) tonnes per £million final demand. Although 'Gas and oil' counts for a larger share of total electricity generation than coal, they emit less direct, indirect and induced CO_2 in their use for electricity production. Both of these technologies have substantially higher multipliers than the original electricity sector Type 1 (Type 2) CO_2-output multiplier of 7993 (8297). The 'Coal' sector's multiplier is around five times the size of the original multiplier in the non-disaggregated analysis while 'Gas and oil' is more than double this value. This illustrates the importance of having a more detailed knowledge of the how electricity is produced and shows why disaggregation of the sector is necessary for exploring the impact of energy policy.

"Electricity supply" is ranked third highest of all the sectors for both Type 1 and Type 2 multipliers with values of 7,995 and 8,339 tonnes of CO_2 per million increase in final demand. As with the previous emissions multiplier analysis the 'Clay, cement, lime and plaster' sector and "Air transport" sector both have significant CO_2-output multipliers and are ranked 4th and 5th respectively.

The smallest CO_2-ouput multipliers are for many of the renewable technologies, by construction, as these have no emissions attached to them from the environmental accounts and therefore their multipliers show only the indirect and induced effects. 'Nuclear' electricity generation does contribute to CO_2 emissions but these are relatively small compared to fossil-fuel generation and so nuclear has a Type 1 (Type 2) CO_2 multiplier of 264 (491). "Nuclear" is ranked 22nd of all 29 sectors for Type 1 calculations and is ranked last of all sectors in the Type 2 calculations where households are made endogenous to the model. The other electricity producing technologies do not have accurate data on their emissions as these are not published in the Environmental Accounts (ONS, 2010a). It is likely that these technologies will be very low in carbon content except perhaps the emissions which occur in their construction and therefore they have no direct emissions in the model.

Figure 4.2: Type 1 and Type 2 CO_2-output multipliers for ten disaggregated electricity sectors (blue and red) and original electricity sector (green and orange)



6. CONCLUSIONS AND EXTENSIONS

It is clear from the above analysis that the electricity sector is considerably heterogeneous in its emissions intensity across the various electricity generating technologies. Therefore decarbonisation of the electricity sector has an essential role to play in helping the UK to reduce emissions and achieve its carbon budgets. Compared to the original aggregate electricity sector both ‘Coal’ and ‘Gas and oil’ electricity generation have substantially larger CO_2 multipliers while many of the other generating technologies have very low carbon dioxide emissions multipliers. Coal generation has a CO_2 multiplier around five times that of the aggregated electricity sector and gas and oil is roughly double. At the same time the emissions multipliers of most of the other generating technologies are very small indeed. It therefore seems obvious that to reduce emissions the most direct method would be for coal electricity generation to be significantly reduced, either through carbon capture and storage or more likely through switching to other lower carbon-intensive technologies whether gas, nuclear or renewables. Although gas would be preferred to coal it is still an emissions-intensive way of generating electricity.

New nuclear power seems to be a likely form of low-carbon electricity in the UK, especially given that it is a proven and cost effective technology. However, there are still safety and political concerns with nuclear and it is unlikely to be the only low-carbon technology to replace fossil fuel generation. Switching from coal and gas to any of the various renewable technologies would be incredibly beneficial for the environment and reduce dependence on imported fuels. However, many of these technologies are receiving subsidies that are of a similar size to their revenues. This makes them an expensive option for producing electricity but one which the Government has deemed appropriate to contribute to meeting their energy policy goals. Further improvements to this analysis could be made if there was more data available on electricity generators purchases and sales. These results should therefore be seen as indicative of the broad heterogeneity of electricity generation in the UK.

Taking both the output multipliers and emissions multipliers into account simultaneously we can begin to understand the effects of energy policy goals. To reduce emissions it appears that retiring coal power stations would be most beneficial. Reducing electricity production from gas and oil would also help to reduce emissions significantly. However, a reduction of gas and oil generation would have a much larger output effect on the economy than coal, in this demand-driven model, given its multiplier effect in terms of the direct and indirect effect on emissions of changes in final demand. This analysis also shows that those sectors receiving subsidies for generating renewable electricity have output multipliers that are larger than would be the case if no subsidy was provided. Therefore it is not possible to take the results from the multiplier analysis of such sectors at face value: in that they partly reflect the current policy stance and would vary with any chance in subsidy. If the subsidy was used to generate output if spent in other sectors there may be a greater economic improvement. Hermannsson *et al* (2012) suggest that government spending in higher education institutions can have significant positive effects on the economy.

It is now possible to use this disaggregated electricity sector IO framework to develop a database which can be calibrated into a general equilibrium model (CGE) model. Further extensions are required in Chapter 5 from the work in Chapter 3 and 4 due to the limitations of demand-driven IO analysis. In order to analyse policy more comprehensively we require a CGE model which can capture supply-side impacts and policies. The IO table forms part of the Social Accounting Matrix that is used to calibrate a CGE model. With a CGE model I can relax a number of limiting assumptions made in IO analysis. A CGE model accommodates more flexible technology and also incorporates an active supply-side which may inhibit output responses to short-run changes in demand. Using such a model would also allow me to track the impacts of policies over time including, for example, responses to the introduction of a carbon tax on sectors of the UK economy. I can model how different carbon tax levels can affect the macro-economy as well as individual sectors and the extent of the tax on substitution between high and low carbon electricity generation technologies.

Chapter 5

A CGE analysis of a carbon tax on the UK economy

1. INTRODUCTION

Analysis in earlier chapters suggested that the use of market mechanisms, in particular a carbon tax controlled by an independent body, may be beneficial in helping the UK achieve its climate change policy goals and ensuring that carbon budgets are met efficiently. In this chapter I further explore the concept of a carbon tax in relation to the work which informed the previous chapters: the EU ETS, the main current climate change policy instrument, and electricity sector, the largest emitting economic sector. The contribution of Chapters 3 and 4 are applied within a pre-existing multi-sectoral modelling framework. I employ a Computable General Equilibrium (CGE) model of the UK economy to simulate the effects of a policy shock, in the form of an *ad valorem* carbon tax, in order to meet the UK GHG emissions reduction target of 34% by 2020 from 1990 levels. A feature of introducing a carbon tax is that it raises revenue which accrues to the public sector. The model therefore compares several different methods of revenue recycling that the government can utilize. In particular I explore the proposition that the carbon tax is revenue-neutral and consider whether a double dividend of improved environmental and economic conditions is possible.

In Section 2 of this chapter I discuss the theory of carbon taxation. This entails a discussion of externalities, a comparison of taxes versus permits, and the possibility of a double dividend. In Section 3 I discuss the current UK climate change policy situation with particular reference to the UK Government’s climate change levy and carbon price floor. I give a general overview of the theory and applications of CGE models in Section 4. In Section 5 I review and discuss previous CGE models which have specifically incorporated a carbon tax in their simulations. In Section 6 I give a description of the model specification which is used in my analysis and the relevant policy shocks that I undertake. Section 7 details the simulations undertaken. I then provide the results of simulating these policy shocks in Section 8 and conclude in Section 9.

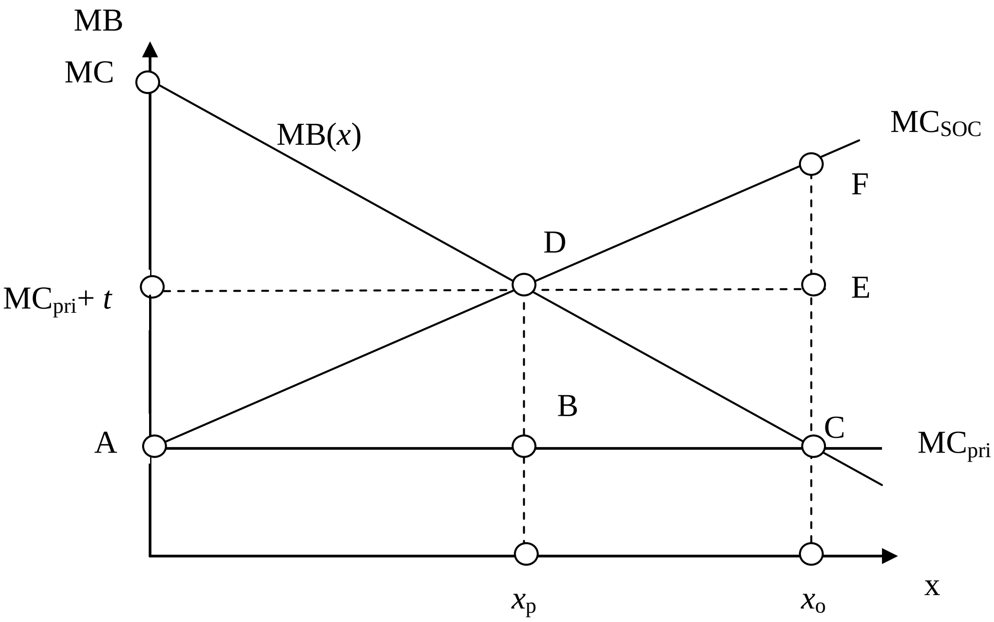
2. MOTIVATION OF A CARBON TAX

2.1 Externailties

The theory of internalising externalities through taxes to achieve a socially optimal outcome was first put forward by Pigou (1938). An externality occurs where the action of a party has a positive or negative effect on a third party who is not involved with the direct action i.e. a side effect. These can be positive in nature e.g. a benefit derived from seeing your neighbour's flowers, or they can be negative in nature e.g. second hand smoke from cigarettes. They often tend to be public goods although it is possible to have private externalities. Baumol and Oates (1988, p.17) define an externality as "present whenever some individual's (say A's) utility or production relationships include real (that is, nonmonetary) variables, whose values are chosen by others (persons, corporations, governments) without particular attention on the effects of A's welfare".

An externality will arise where the total social costs and benefits of the externality are not reflected directly in the price of the action or good. The original party will only take into consideration the private costs and benefits of their action. For instance a producer may cause pollution through its production that result in external costs to others e.g. health effects. The producer's profit maximising decision making will only consider their revenue and total costs but not the effects of the pollution on others. In this case the private cost is less than the social cost and so the firm's output will be greater than its socially optimal level, which exists where social marginal benefit equals social marginal cost. That output is greater than its socially optimal level is a market failure. There will be greater pollution, and therefore greater negative effects, than is optimal. The problem arises because the interaction is not mediated through a market and therefore the state may have a role in correcting this market failure by either creating a market or replicating the effect of such a market through appropriate taxes or subsidies. Pigou suggested that taxes on negative externalities or "bads" should be set as the difference between the marginal private benefit to the individual and the marginal social benefit. Employing such a tax would therefore ensure that the welfare of the entire economy was considered in the decision over whether to undertake the action that generates the externality. There is then a role for governments to consider applying taxes or subsidies in situations when externalities, which negatively or positively affect others, are not explicitly incorporated in market decision making.[95]

Figure 5.1: Pigovian tax



Source: Adapted from Schöb (2003)

In Figure 5.1 a consumption good x which contributes to climate change is considered. MB(x) is the marginal benefit of consumption while MC_{pri} and MC_{soc} are

[95] For a formal analysis of externalities see Baumol and Oates (1988) chp. 4

the marginal cost to producer and society, respectively. With no environmental regulation the market equilibrium output level is x_o. At this equilibrium point the welfare loss to society is the area CDF because in that area MC is always greater than MB above the point x_p. However, increased output up to the point x_p increases society's welfare. A Pigovian tax of rate *t* will achieve this equilibrium level of output of the polluting good x_p. This tax will generate revenues of the area $ABDMC_{pri}+t$ which can be used for a number of purposes discussed later.

Climate change is a particularly good example of such a negative externality and the climate is clearly a public good, therefore it is a relevant situation for the government to consider the social costs. The effects of climate change and issues surrounding the global nature of the problem are discussed in more detail the Introduction (Chapter 1). In theory, by employing a Pigovian tax on polluters of dangerous greenhouse gases the tax can achieve the optimal level of emissions which will be the level that minimises the total abatement costs plus total damage costs of emissions (Perman *et al*, 2003). Essentially a tax is levied on the polluters for any pollution emitted which is set at a rate that equalises the marginal abatement costs i.e. the cost of reducing another unit of emissions, for all producers and therefore achieves the emissions reduction at least cost. The polluter will internalise the price of carbon in its decision making process and respond accordingly by reducing output or investing in a more cost-effective and less emissions-intensive production process.

Setting this tax rate, t, is not easy to calculate in practice where uncertainty is prevalent as there are two main problems: a) it requires knowledge, and discounting, of future benefits and costs in order to set the tax level now and over time in order to ensure credibility, and b) it requires accurate monitoring of emissions which cause climate change, in order to tax them. The easiest way practically to overcome this second issue would be a tax levied on the carbon content of the use of fossil fuels. This would incentivise the substitution from heavy polluting to low-carbon technologies.

2.2 Prices and Quantities

Overcoming a market failure using a market instrument need not necessarily be done by setting a price; it can also be done by setting a quantity. Permit trading, therefore, can play the same role as taxes. The details of permit trading under the EU ETS have been briefly described in Chapter 3. Under the assumption of perfect information either a tax or permit trading will achieve the same outcome of overcoming the market failure in a cost effective manner. The alternatives are that in a permit scheme quantity is fixed and price are allowed to adjust or for a tax you fix the price, as an additional mark-up to marginal cost, and allow output to adjust. Either way the overall outcome with perfect information would be the same under a tax or permit system in that firms would eventually adjust until marginal abatement costs of all firms would be equal. However, in reality we are often faced with imperfect information and considerable uncertainty. There has been considerable discussion as to whether permits or taxes should be used as the method to combat climate change and it is worth quickly discussing these arguments given the considerable uncertainty of climate change.

Weitzman (1974) was the first to discuss the merits of price against quantity mechanisms, and vice-versa, in a general setting under uncertainty. His model explained that which instrument is more appropriate is determined by the slopes of the marginal benefit function and the marginal cost function of the particular market failure. These functions describe the extra benefit and the extra cost (damages) to society as the amount of emissions in the economy is changed. Weitzman assumed that the random error for uncertainty was so small as to have quadratic approximations of generalised total cost and total benefit functions, and therefore linear approximations of marginal cost and benefit functions. He compared welfare results for prices and quantities and the results produced the expression for the comparative advantage of prices over quantities as:

$$\Delta = (\sigma^2/2C^2)\,(C\text{-}B) \qquad (5.1)$$

where σ^2 is the variance of the shocks to the marginal cost schedule, C is the slope of the marginal cost schedule, B is the slope (normally negative) of the marginal benefit schedule The main result was that price instruments were more appropriate where the marginal benefit was relatively flat ($\Delta > 0$ when $B < C$) and that a quantity mechanism was more favourable when the marginal cost were relatively flat ($\Delta < 0$ when $B > C$). This result is dependent upon uncertainty of marginal costs.[96]

In relation to climate change the general consensus is that it is likely that the marginal cost of emissions reduction rises quickly while the marginal benefit of emissions reduction is small over short time periods (McKibbin and Wilcoxen, 2002). The marginal cost of reducing emissions is relatively steep for most nations while the marginal benefit curve of reducing emissions is very flat because damages of climate change are caused by long-term stock of emissions over several decades. Therefore, under this sort of Weitzman analysis, the case for carbon tax over permits is strong. However, the longer the time period considered (say from 5 years to 50 years) then the more quantity mechanisms become favourable as the slope of the marginal benefit function increases (Hoel and Karp, 2002). Much of the literature has focussed on the costs of climate change under uncertainty although assumptions about the benefits are important too (Stavins, 1996). Pizer (2002) finds that price mechanisms are the more efficient instrument choice for climate change where there is considerable uncertainty with regards to costs. He uses a stochastic extension to a deterministic climate-economy model based on Norhaus (1994) which incorporates cost, benefits and uncertainty of mitigation to find that expected welfare gains from optimal price policy is five times as high as the same from a quantity policy. This result occurs due to the relatively flat marginal benefit curve assumed. When an alternative assumption of catastrophic damages is assumed then quantity controls are preferred.

[96] For a textbook discussion of pollution policy under uncertainty see Perman *et al* (2003) Chp. 8

Hepburn (2006) reviews the use of instrument choice, with a short section particular to climate change and the practical issues involved for both instruments. Permit schemes have been preferred in practice to achieve environmental aims. The grandfathering of permits, the success of the SOx and NOx permit schemes in the US as well as a general aversion to new taxes has made permits schemes more politically acceptable. Given that the EU ETS already exists then it is unlikely to disappear due to the institutional lock-in. The way forward may be a hybrid scheme. Helm (2010) argues a second reason why taxes should be preferred to permits for carbon over and above the Weitzman-style analysis. He emphasises the impact that so-called ‘policy costs’ will have on the argument of instrument choice. He believes that the costs of reducing climate change are severely underestimated because there is so much scope for capture and rent-seeking behaviour involved. Given these political economy issues Helm believes that “If climate change is urgent then taxes are much faster and more immediately effective than permits” (Helm, 2010, p. 60)

However, in practice permit schemes have tended to be used because they appear to be more politically acceptable than a carbon tax. Companies are more willing to accept permits, rather than an indirect tax, especially where their allocation is grandfathered rather than auctioned.

The model used in this chapter does not consider uncertainty and therefore the simulation results would be identical whether price or quantity instruments were employed. It is assumed that the market mechanism is employed by the Committee on Climate Change (which negates any uncertainty through its credibility i.e. complete certainty is assumed). The rest of the chapter is concerned with a carbon tax because it appears to be coming into favour as a policy instrument in the UK and would definitely raise revenue which is an important consideration.

2.3 Effects of a carbon tax

The concept of creating a price of carbon, either through taxes or permit trading, has been discussed by academics and policy-makers at considerable length over the past few decades and in particular since the UN Framework Convention on Climate Change in 1992. Implementing such a carbon price by using a tax will obviously have positive and negative economic effects, all of which must be considered by policy-makers.

The extent to which the introduction of a carbon tax will affect the economy will depend on the opportunities for abatement. Firms who are now incentivised to reduce emissions through increased costs of their inputs have three options. They can change their input mix, use different technology processes to limit emissions from production, or reduce output. A combination of all three is likely. Where abatement is not possible these firms only option will be to reduce their output if in a perfectly competitive market. Thus the cost of a specific reduction in carbon emissions can be measured as the costs of abatement plus the value of any foregone output (Ekins and Barker, 2001).Consider production in one emissions-intensive sector e.g. energy. There will be a substitution away from emissions-intensive inputs, where possible, towards inputs with a low-carbon producing content. For instance, in the production of electricity, suppliers may substitute away from coal to use gas, nuclear or renewables which have much lower carbon content and are therefore less emissions-intensive. Where this substitution is not possible we would expect a carbon tax to reduce the supply of energy and goods with energy inputs because the price of carbon has been internalised and therefore the price of fossil fuel inputs to energy have increased. Therefore energy will be relatively more expensive and this will be passed on to consumers. The general equilibrium price elasticities of demand and supply for energy will determine the extent to which the output of this sector is reduced and therefore the extent of emissions reduction.

In terms of the market for labour we would expect the carbon tax to have the following effects. Holding everything else constant, the reduction in overall output of emissions-intensive sectors due to the tax would also reduce demand for labour as an input. Also, theoretically, as the price of emissions-intensive goods increases e.g. energy, the real wage would be lowered (and assuming no increases in wages), and so in the trade-off between labour and leisure this would make leisure slightly more attractive, thus lowering the supply of labour. Simultaneously, the increase in the price of such emissions-intensive goods would lead to substitution from energy to other value-added where possible, depending on the elasticity of substitution between intermediate inputs and value added, and so tend to increase labour inputs within these sectors where substitution is possible.

There are a number of competing effects on output and employment in the economy although some sectors will be affected more than others. Some sectors, such as low-carbon or emissions abatement technologies, may see an increase in their output. It is likely that these macroeconomic effects will be negative overall. When discussing the effects of an environmental improvement through a carbon tax, Ekins and Barker (2001, p. 333) remark that "a loss of marketed output is to be expected from such an improvement unless the instrument of improvement permits the reduction of other, pre-existing, economic inefficiencies". Therefore, in terms of macroeconomic effects, a reduction in emissions is generally associated with a contraction in overall output and employment in the economy. Revenues will be obtained from the carbon tax and how these revenues are distributed will have further effects on the economy. They could be used to subsidise low-carbon technologies, or to achieve other government goals such as deficit reduction, or to reduce other existing taxes.[97] We leave a discussion of the most likely form of how revenues are recycled until the next section.

Ekins (1994) also distinguishes three effects of a carbon tax that are harder to model: investment, efficiency and technological change. The change in relative prices brought about by the tax may influence investment as new cost-saving opportunities are created and this investment will increase GDP. Investment in areas of energy efficiency and renewables may allow the tax rate to be less than otherwise required. The carbon tax may also bring forward the scrapping of existing capital equipment. All of these effects will be captured within a general equilibrium framework but it is difficult to say ex-ante what the extent of these effects will be.

[97] This is assuming that revenues are raised. It is possible that the tax could achieve total abatement through complete substitution away from emissions-intensive inputs in the economy in which case nobody would pay the tax.

2.4 Advantages of a carbon tax

Pearce (1991) discusses what the main advantages and disadvantages are of using a carbon tax to reduce emissions in order to combat global warming. One advantage of using a carbon tax is its flexibility in so far as the tax level can be modified easily when new information, whether scientific or economic, is presented which may make it more flexible than a permit trading system. Taxes can provide revenue for government which is especially important now given considerable national budget deficits. It may be politically easier to introduce a new environmental tax levied on firms than it is to increase income taxes. Taxes are easier to administer than permit trading schemes. Also, carbon taxes should help stabilise volatility of the carbon price more than permit trading schemes where the price can vary, often significantly, due to changes in demand for permits.[98] A trading scheme sets the quantity and allows the price to fluctuate whilst with a tax the price is certain but the quantity of emissions fluctuates. Therefore taxes unquestionably result in less price variation than quantity mechanisms such as permit trading.

However, many environmental scientists consider quantity certainty more important with climate change because it is the *amount* of emissions that cause temperature rises. Therefore setting a quantity for emissions and making sure this is not exceeded seems a sensible approach. Unfortunately though, where quantity setting leads to price volatility then the credibility of the trading scheme may be undermined. Fluctuations in the carbon price under a trading scheme may cause uncertainty and price certainty is extremely important for investors in low carbon technologies. Therefore a tax may well lead to higher investment than under a permit scheme but with less certainty that emissions targets will be made.[99]

A market mechanism to reduce emissions that raises revenue, such as a carbon tax, is considered more preferable than an instrument which raises no revenue whatsoever,

[98] See Metcalf (2009) for a discussion of carbon taxes from a US perspective.
[99] Although this assumes credibility of the tax level over the long-run

such as regulation, or where profits simply accrue to industry, such as under emissions trading where permits are grandfathered. The revenues from such instruments can be used to promote efficiency and achieve government objectives. In particular, Pearce (1991) highlights that one of the potential benefits of a carbon tax is that it may provide a ‘double dividend’ by not only reducing the bad of pollution (first dividend) but also the increase in revenues from the carbon tax can be used to reduce the distortionary effects of other taxes which are normally levied on factors of production and actually improve welfare (second dividend). It is argued that it is better to inflict this loss upon a “bad” such as pollution, which has a larger social cost, rather than a “good” such as labour, capital or investment. Where taxes are levied by the government to finance public goods, these taxes will distort prices regardless of what they are levied on. But if the government taxes a negative externality then this reduces the real cost of funding public goods. Therefore employing a tax on labour causes a deadweight loss to the economy whereas levying a tax on pollution will realign incentives to those of the whole society. Therefore, in a first-best situation, where neither tax exists initially, introducing a tax on pollution is preferred to a tax on labour.

Initially those considering carbon taxes were unconcerned with other distortionary taxes, assuming that revenues would be returned to consumers in a ‘lump-sum’ manner. Consumers would have a lower real income from the carbon tax but this would be returned to households to stimulate consumption. In a perfectly competitive equilibrium without any pre-existing taxes, this method of recycling would minimise any distortions in the economy but it is not the most likely method of returning revenues in practice. However, practical considerations soon turned attention on to how revenues of a carbon tax could be recycled in various other ways to reduce pre-existing distortions. Many commentators suggested that the revenues could be used to reduce other distortionary taxes such as employer’s social security tax or corporation tax, or employee’s income tax. This offset would ensure that the revenues of a carbon tax could be redistributed in a fiscally neutral manner, lower the costs of the tax and may increase employment and income when a carbon tax and a reduction in labour tax are introduced simultaneously. There is no exact definition of what a double dividend entails but it can be thought of generally as an environmental improvement (first dividend) together with an economic benefit (second dividend); normally an improvement in welfare where employment or GDP are used as indicators (Bosquet, 2000). A complete discussion of the double dividend theory is beyond the scope of this thesis but a brief further discussion is required.

2.4.1 Double Dividend hypothesis

It may appear that a carbon tax is beneficial as it will always generate a double dividend and improve both environmental and economic conditions. This would seem like a free lunch for policy-makers who can introduce regulations without any overall negative impact. However, a substantial theoretical literature which arose after the initial idea of the double dividend suggests that in a second-best world, where other distortionary taxes already exist, a double dividend will often not be found (Bovenberg and de Mooij, 1994; Bovenberg and van der Ploeg, 1994; Goulder, 1995; Parry 1995; Parry and Oates, 1998). A clear result of many of these papers is that the optimal tax in a second-best setting is lower than the Pigovian tax rate in a first-best case where no other taxes exist. However, these analytical models impose a number of assumptions including, but not limited to, the following: consumption goods are perfect substitutes for leisure; households receive disutility from pollution and the utility function is restricted to make environmental damages separable; and labour is the only primary factor input. The extent to which these assumptions are applicable is discussed in Parry (1998) and he states that where the assumptions are relaxed or made more realistic e.g. capital is introduced to the model; then there is a greater chance of a double dividend occurring as more flexibility is introduced to allow more substitution possibilities.

Goulder (1995) provides a useful overview of the issues involved regarding environmental taxation and a possible double dividend. He states that a double dividend is often achievable but whether it arises will depend on the specific situation. Three important considerations as to whether a double dividend is possible are the extent and workings of the original distortionary tax; the method of revenue recycling, and also what measure of economic improvement is considered to be the second dividend – an increase in employment, economic activity or welfare. Goulder (1995), Bovenberg (1999) and Takeda (2007) distinguish between different strengths or forms of double dividend hypothesis which can be defined. Firstly, a *weak* double dividend is where returning tax revenues through a reduction in other distortionary taxes is more welfare enhancing (cost saving) than returning the revenues through lump sum transfers. This denotes a situation where recycling revenues through cutting distortionary taxes is more efficient than having revenues accrue directly to industry through grandfathered permits. Secondly, a s*trong* double dividend occurs where swapping an environmental tax for a representative (or typical) distortionary tax involves a zero or negative gross efficiency cost. That is to say, not only is there an environmental benefit but also the non-environmental costs, alone, are negative. The gross efficiency cost is all other effects other than the environmental change. The weak form is generally taken for granted by economists but whether the stronger form holds is often debated. The difference between the two is that while the weak version compares two policy changes, the strong version compares a policy change with no change whatsoever (Bovenberg, 1999). Whether or not the strong dividend holds will depend on whether the cost from introducing the carbon tax is bigger or smaller than the cost savings from reducing the distortionary tax. However, in the model simulations in this chapter a double dividend is simply classified as an increase in either GDP or employment from the base year equilibrium level. These are used as proxies for a non-environmental welfare increase.

Goulder (1995) and Parry and Oates (1998) identify three main effects generated in analytical models of a carbon tax in which revenue is recycled through reductions in social security contributions of employers, that determine whether a double dividend is possible. Firstly, there is the "*primary welfare* gain". This is the environmental benefit (net of costs) of the reduction in emissions. Although it is often not measured in monetary value, this effect can be seen as correcting an already existing distorting externality and therefore improving welfare.

Secondly, there is a "*revenue-recycling* effect" which occurs when revenues are returned through reductions in pre-existing distrortionary taxes. This will be a welfare improvement gained due to the reduction in the price of labour from the lowering of employer's national insurance contributions - which is a pre-existing distortion - using the revenues from the carbon tax. By reducing the difference between the gross and net wage this should lead to an increase in employment and also raises real income in the economy.[100]

Thirdly, there is a "*tax interaction* effect" which combines the initial effects of the carbon tax that reduces output (discussed above) with other considerations such as how the taxes affect each other. As discussed above, given that distortionary taxes already exist, then the introduction of a new carbon tax will increase the costs of production which are passed on to consumers in higher prices and reduce the real wage of households and reduce worker effort. Also, the two taxes (social security and carbon) will interact with each other in a general equilibrium setting due to cross-price effects which can increase pre-existing distortions. A tax on labour will not affect the relative consumer prices of goods as much as a carbon tax will if labour-intensities are less disparate than carbon-intensities across sectors. Another important consideration is that the tax base of each tax is important in determining the size of the *tax interaction* and *revenue recycling* effects. The labour tax will have a much larger tax base than the carbon tax, which, depending on which goods it is levied upon, will have a narrow tax base. The yield of the environmental tax is lowered as consumers substitute away from the taxed commodity, which is easier to substitute away from than the labour tax, and this will affect the extent of the *revenue recycling* effect. Therefore the elasticity of substitution between dirty and clean goods will be critical not only to the extent of the environmental benefit but also the size of tax revenues which in turn determines the ability to reduce distortionary taxes.

This "*tax interaction* effect" usually, but not always, works in the opposite direction to the "*revenue recycling* effect" and whichever is larger will determine whether a

[100] Where revenues are used to reduce income taxes then this will raise the disposable income of employees.

second non-environmental dividend is achieved. This is the question that academics and policy makers working on this area are concerned with. Barker and Ekins (2001, pp. 337) in summing up these effects state that "the possibility has been addressed in a number of papers that, through interdependencies in the tax system, or the erosion of the environmental tax base, the reduction of the environmental distortion in the context of a labour market with pre-existing labour taxes could lead to more labour market distortion rather than less". The extent of these *revenue recycling* and *tax interaction* effects, and therefore whether a double dividend occurs, will significantly depend on the existing tax system and the economy in question as well as the details of the new carbon tax (Takeda, 2007). Bovenberg (1999) concludes that the strong double dividend will hold in instances where the initial tax system is not optimal from a non-environmental viewpoint.

Parry and Oates (1998) stress that the workings of the labour market are of particular importance in the double dividend debate. That in practice the labour market is complex and uncertainties exist whereas in theory it is often treated as a single, competitive market. Bosquet (2000) stresses that "one important caveat is that for employment gains to materialise, the labour market must be flexible". Ekins and Barker (2001) compare a number of studies and notice that in general it is more difficult to achieve an increase in GDP above base in the US from recycling through employment taxes than it is in other countries. This is explained by the fact that the US is closer to full employment and already has lower employment taxes than places like Europe. The closer an economy is to having a vertical labour supply curve then they will find it more difficult to achieve employment increases and possibly a double dividend. Schwartz and Repetto (2000) propose that a cleaner environment may have a positive effect on labour supply which may partially offset the reduction in real wages from the carbon tax and therefore the assumption that environmental quality is weakly separable in the utility function should be relaxed in the analytical models. Trade effects are also important to consider with regards to overall welfare in an open economy as taxes on products will make them more expensive and thus exports of these products will fall and imports will increase.

One question that arises from this analysis is that, if a carbon tax does achieve an increase in GDP in a country from recycling that reduces employment taxes, then why hasn't this been implemented regardless of whether the first environmental dividend is achieved? Or to put it another way, if the second dividend (non-environmental improvement) of a welfare improvement is possible then why has it not been undertaken already. The motivation of the tax is crucial here. Could it be that the government utility function has changed and only now that it considers both environmental and growth goals does it consider the introduction of a new tax beneficial. One possible reason that it could not be introduced previously is that it would be seen as unfair or less equitable to levy tax on a specific sector but that it can now be justified through environmental motives which have strong political backing.

Bosquet (2000) concludes from a review of the theoretical literature that each potential environmental tax must be considered independently to verify whether a double dividend is possible. He reviews the results of 131 simulations of 56 studies on how environmental taxes affect emissions, employment, GDP, investment and consumer prices. His survey finds in general that carbon emissions are significantly reduced; there are marginal gains in employment and marginal gains or losses in production over the short to medium term, and investments decrease while prices increase moderately (Bosquet, 2000). These results are from a wide variety of CGE, partial equilibrium, macroeconomic and Input-Output models and for a number of different types of taxes and various tax levels, therefore they give only an aggregate indication of model results. A similar meta-analysis is conducted by Patuelli *et al* (2005) which has comparable findings. In section 5 we discuss the double dividend literature further in reference specifically to CGE models.

2.5 Disadvantages of a carbon tax

Pearce (1991) also discusses the disadvantages of a carbon tax. As a market mechanism taxes are a price instrument whereas emissions reductions are a quantity based outcome. This is why permit trading schemes are in principle a more precise way of reducing CO_2 emissions. A tax cannot make sure that emissions do not exceed a certain level which may be especially important where a tipping point can lead to severe irreversible consequences. Specifically, in order to set the correct tax level the price and income elasticity for carbon-intensive goods must be known. While flexibility in being able to change the tax rate may be beneficial in one sense, in another it may reduce the value of the tax as an investment signal because investors will under-invest if they do not believe in the credibility of the tax level over the time frame of their investment. This was discussed extensively in Chapter 2. Also, inter-fuel substitution elasticities are required to inform the appropriate tax rate. The tax base may change over time once the tax is implemented and this can reduce revenue. A carbon tax may also be regressive as increases it increases energy prices. Any policy which does this will have distributional effects and may adversely affect poorer households, who spend a greater proportion of their income on energy, more than those with higher incomes. Therefore other policy measures or transfers aimed at fuel poverty may be required to offset this effect.

Given that the climate change issue is a global problem then an international carbon tax would be most appropriate. However, given national sovereignty and revenue raising concerns, this is extremely unlikely. Any such carbon tax will more likely be implemented at a national or regional level but this brings its own issues. There is very little incentive for individual nations to reduce their carbon emissions on their own because unless all countries coordinate then the climate will not be affected. Countries have the incentive to free-ride on other nation's efforts. This is true regardless of what control mechanism is applied at the national level. The free rider issues of climate change are well documented in Finus (2006). Gradual harmonisation of national policies would be the most likely way forward.

There are also competitiveness concerns over implementing national carbon taxes if they are not adopted by other nations simultaneously. Carbon-intensive industries may become susceptible to unsustainable levels of competition if similar industries in other countries can import products at lower prices because they are not liable to pay the carbon tax. This may cause industries to relocate to nations with less strict regulation and the emissions, which the carbon tax intends to reduce, will take place anyway in another location. Therefore a carbon tax may be used as a method for individual countries to achieve their own country's emission reduction targets but overall it may have a neutral effect on worldwide emissions levels which cause climate change. These emissions may even increase if technologies used are less efficient in those nations to which the industries move and in which the carbon-intensive products are now produced. This is a concern for all nations who have their own climate change policies. However, it may be possible to offset some of these effects by introducing a border import tax in order to tax the carbon content of imports and ensure consistency of the tax; not imposing a border tax is essentially an import subsidy (Helm, 2010). How such an import tax is implemented in practice is difficult to decide and there is debate as to whether such a tax would be against WTO rules. There are also general competitiveness concerns within each nation in that, with a balanced budget, when you increase taxes on certain industries you may wish to reduce other taxes on that industry, especially those industries that are most negatively affected by the tax. The introduction of a carbon tax will change relative prices and therefore affect international competitiveness of industries depending on many factors including: the size of the tax; the carbon intensity of the good; and how susceptible the good is to trade (Ekins, 1994).

3. UK CARBON TAXATION

Environmental taxes accounted for 8.3% of total UK tax revenues in 2004. These taxes can be split into three categories: energy, road vehicles and other environmental taxes. [101] Added to these, the UK is soon to introduce a carbon price floor (HM Treasury, 2010). This will function alongside the existing EU ETS price in order to create a stable price of carbon to create support and certainty for low-carbon investors in the UK. A hybrid of taxes and permits will exist. The Government believe the price support will increase incentives for low-carbon

[101] Energy taxes include duty on hydrocarbons e.g. petrol, as well as the Climate change levy and Renewable Obligation. Other environmental taxes are the Landfill tax, Air Passenger duty and Aggregate levy

technologies by signalling Government commitment to a low-carbon economy; reducing the uncertainty of revenue and investment risk; and increasing carbon intensive technology costs. These two instruments, the EU ETS and the carbon price floor, will exist simultaneously to keep the price of carbon above a minimum in the UK, so when the EU ETS permit price becomes low the UK tax will assure investors by stabilising the price. This comes as part of a series of electricity market reforms (EMR) announced by the Government in 2010. The carbon price floor is intended to provide a credible price of carbon in the UK over the short to medium term and can therefore be viewed as a method for government achieving their carbon budgets set by the CCC. The proposal is to modify the Climate Change Levy (CCL) and fuel duty on fossil fuels used in electricity generation in order to supplement the carbon price. Therefore it will apply to a quite substantial subset of the EU ETS but will not have the exact same coverage.

Helm (2010) gives an argument for introducing a price floor to the EU ETS. He believes that the EU ETS has three main problems. It is short term in nature, with a volatile price that is also too low. He says that since it is infeasible to scrap the EU ETS, and introduce a tax, due to political interests, then a carbon floor and ceiling should be incorporated into the EU ETS. He believes that these can be argued firstly, on a theoretical basis; that the cost and damage functions may have different shapes over various parts (Roberts and Spence, 1976). Essentially it may not be as simple as one function always being steeper than the other and over different ranges the relative slopes may differ. Therefore, in relation to the Wietzman (1972) discussion on prices versus quantities under uncertainty referred to above, a permit scheme may be more appropriate where marginal costs are relatively flatter than marginal damages i.e. where a small increase in emissions causes massive temperature rises. However, above and below the portion where marginal costs are flatter, a tax would be appropriate because the marginal costs are steeper and so any extra emissions reduction will impose large costs if the price of carbon is wrong. I am not wholly convinced of this theoretical argument. Firstly, with regards to above the range, it is unlikely that marginal damage functions will become less steep above a certain range. It is likely that only more extreme catastrophic events will occur and so a price mechanism above a range is unnecessary. Secondly, with regards to below the range, it is certainly plausible that abatement becomes more costly as more emissions are reduced. Emissions that are easiest and cheapest to abate will be undertaken first and so the marginal cost function may begin flat and rise sharply after a certain level of emissions abatement, although improvements in technology may partially offset these increasing costs.

Helm believes their introduction can also be argued on pragmatic grounds, in that credibility is added to the scheme by incorporating a price ceiling and floor. A price ceiling stops severe harm being done to consumers by high prices that would be a concern to politicians. A price floor will create more certainty for low carbon investments by not allowing the price to fall below a minimum level. This practical consideration seems the more convincing and the concepts of certainty and credibility are issues that arise often in respect to climate change policy.

The price ceiling idea seems unnecessary in the EU ETS context currently so we concentrate here solely on the price floor concept and how it could be implemented. A price floor should help to solve the issues of volatility and low average price. However, Helm believes it is unlikely a floor would be paid for centrally because governments would be hesitant to allow tax revenues to be determined and received at the EU level and so this must be determined outside the EU ETS. He therefore recommends that the UK Government introduce an upstream fuel tax on the main fossil fuels based upon their carbon content. This would approximate as a price floor for the EU ETS across the UK. For the tax itself he states that it should start low and rise over time. This appears to contradict previous literature that suggests high tax rates that reduce over time (see Ulph and Ulph, 1994). Perhaps this is because it is more politically feasible. [102] Helm (2010) also asserts that the tax must be credible over a long time and suggests three possible options: first, the “institutional inertia” of the Treasury; second, a long-term cross-party agreement not to lower the tax; or

[102] It should be noted that there was a previous attempt at a fuel duty escalator in the UK in which fuel prices were increased over time. However, this policy eventually had to be abandoned due to a strong public backlash against sharply rising prices.

third, ask the Committee on Climate Change to set the tax rate. I previously discussed the possibility of the latter in Chapter 2.

3.1 UK Climate change levy

The CCL is a tax on electricity, gas, solid fuels and liquefied petroleum which was introduced in 2001 and applies to these commodities when they are supplied to business or public sector (not households and transport). Therefore it is a tax on energy used by firms and the public sector. It was introduced following the Marshall Report (1998) as a way of reducing greenhouse gas emissions and promoting energy efficiency in the business and public sectors. It has different levy rates for the various fossil fuels used as energy sources. The rates are based on energy content and not carbon content. They are levied on pence per kWh for electricity and gas and on a weight basis for coal. Both gas and coal are taxed at the same rate even though coal has much greater carbon content and therefore emissions potential. This seems counterintuitive as a method to reduce carbon emissions.

As a policy the levy is heavily influenced by the double dividend literature (Pearce, 2006). A substantial amount of revenues are recycled back to payers of the CCL through reductions in employer National Insurance Contributions. Some of the revenues are also used to fund the Carbon Trust. In order to protect competitiveness, several energy intensive sectors have substantially discounted rates of CCL, up to 80% reductions, where they undertake Climate Change Agreements (CCAs) to meet specific government targets. These discounts are given as long as the overall sector meets its target. For instance, the horticulture sector is given a 50% discount purely because it has many small companies and is liable to international competition. Also, the targets set under the CCAs do not appear to be particularly challenging. Of the CCA targets set, only one sector’s target in one year would have been missed under business as usual assumptions (McIlveen, 2010) and so their use appears to have little effect at all.

There are also several exemptions to the CCL. Fossil fuels used in electricity generation are completely exempt from the CCL and oils are exempt from the CCL but are liable for fuel duty when leaving the refinery. Currently fuel duty can be reclaimed by oils used to generate electricity but the EMR wish to reduce the amount reclaimable in line with the carbon price support rates. One major criticism is that nuclear power is not exempt even though it is a low-carbon energy source. A detailed analysis of the CCL is beyond the scope of this thesis but Pearce (2006) discusses the reasons why the CCL differs in practice from what a theoretical energy tax system would suggest. Varma (2003) examines the cost effectiveness of the CCL as well as implications on competitiveness and its environmental impact. However, this paper was written just as the CCL was put in place and so is not comprehensive. We are primarily concerned with the new carbon price floor and the effect it will have on the UK economy, in particular whether it may provide a double dividend.

3.2 Carbon price support rates

The carbon price support rates will be levied on suppliers of fossil fuels to electricity generators and will differ for each fuel. The main aim is to maintain a stable carbon price that encourages investment in low-carbon technologies. This will be done by removing the current exemption to the CCL of fossil fuels used in electricity generation. The Budget 2011 announced the introduction of the carbon price floor in 2013 which will start at around £16 per tonne of CO_2 and rise to £30/tCO2 in 2020 and £70/tCO_2 in 2030 (all in 2009 prices). It is expected that the rate will rise about £2/tCO_2 each year from 2013 to 2020. To achieve this floor a carbon price support rate is to be introduced to supplement the EU ETS price which is currently sitting around £11/tCO_2. These support rates will be set at the difference between the intended price floor and the futures market for carbon in the EU ETS. The support rates will be equivalent to £4.94/tCO_2 in 2013-14 and rise each year as needed to maintain the price floor. The rates for each year are set two years in advance in the budget. The carbon price support rates will be calculated by the following formula:

Box 5.1: Carbon price support rate equation

Price floor Rate = (Target carbon price – Market carbon price) x (Emission factor of the fuel)

Source: HMRC (2011)

This formula at least means the emissions factor of the fuel will be considered when the price floor is implemented, unlike the CCL, making it a carbon tax rather than an energy tax. The standard emissions factor for gas is around 0.000184 tCO_2 per kWh. This emissions factor is then multiplied by £4.94 to give the support rate for gas of £0.00091 per kWh.

Table 5.1: Carbon price support rates from 1 April 2013

Supplies of commodity	Rate April 2013 to March 2014	Unit
Gas	£0.00091	per kilowatt hour
Liquified petroleum gas (LPG)	£0.01460	per kilogram
Solid Fuel (e.g. Coal or coke)	£0.01188	per kilogram
Fuel oil	£0.01568	per litre
Gas oil	£0.01365	per litre

Source: HMRC (2011)

However, the fact still remains that the price floor, which applies to fuels sold to electricity, is already covered by the EU ETS. This means that any reductions in emissions due to the floor will allow more emissions elsewhere in the EU. Therefore there is no impact on overall emissions in the EU. The tax base of the UK carbon price floor is relatively narrow – a large subsection of the EU ETS. A carbon tax which targeted non-traded sectors would be more successful at reducing emissions although this may be harder to implement in practice. The tax could even cover the entire economy i.e. traded and non-traded sectors. There is also a concern that the carbon price floor will increase substitution to imported electricity however the extent of this is currently limited by interconnection capacity (HMRC, 2010). Given its unilateral nature, there are also serious concerns that this carbon price floor will damage UK competitiveness with the rest of Europe, as well as the rest of the world, in industries that use large amounts of energy inputs. Hopefully these effects will be offset somewhat by making the UK a more attractive place for low-carbon investment. Also, whether the government is able to commit to these levels of price floor rate over time remains to be seen. Any deviation away from these levels will affect credibility of the policy and therefore incur under-investment in low-carbon technologies.

I therefore consider it appropriate to attempt to create a model that could capture the effect that such a tax, and its potential rates, would have on the UK economy but with particular reference to the electricity sector and its various generation technologies. I wish to attempt numerically to model the possible implications of a carbon tax policy instrument on the UK economy. Given the economy-wide effects of a carbon tax then partial equilibrium analysis is not appropriate and a general equilibrium approach is required (Pearce, 1991). Interaction and substitution between economic sectors is essential as to the outcome of any environmental policy. In order to achieve this it is also necessary to move beyond the IO analysis which has been used in previous chapters. IO analysis assumes that the supply-side of the economy is passive i.e. that supply can meet any change in demand. It also assumes that there is universal Leontief technology and therefore cannot allow substitution in production if prices change. This is not realistic when we wish to model supply-side changes such as the imposition of a carbon tax. I therefore employ a Computable General Equilibrium (CGE) model as this allows analysis of the effects of policy on the economy as a whole while modelling both supply and demand behaviour and simultaneously allows us to capture recycling of revenues within the model.

4. COMPUTABLE GENERAL EQUILIBRIUM MODELS

In this section I briefly discuss what a CGE model is and how it functions. This entails an overview of the theory; a description of a general CGE model; an illustration of their strengths and weaknesses, and how they are applicable to policy analysis, in particular environmental policy.

4.1 CGE theory and background

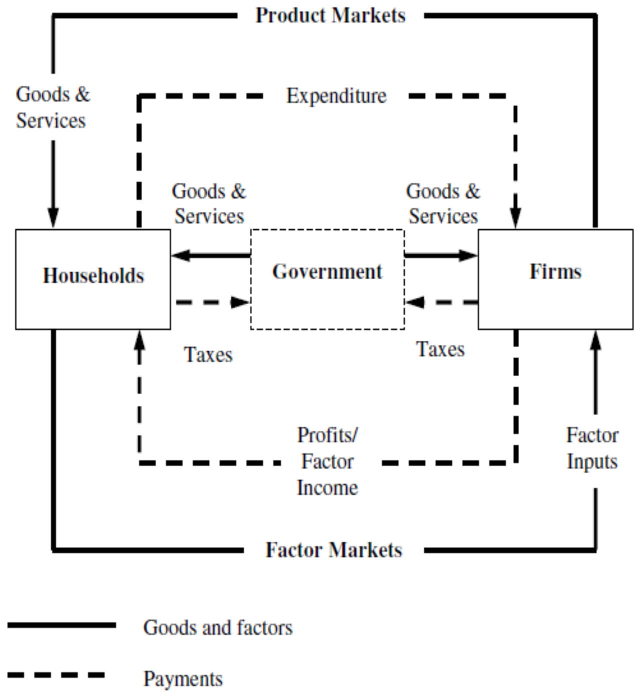
CGE models are based upon Walrasian general equilibrium theory and attempt numerically to recreate the theory using structural data and parameter values from an actual economy. A general equilibrium theory of an economy is represented by a system of simultaneous equations representing markets clearing conditions in which equilibrium exists where supply equals demand in all markets, for a set of prices and quantities of production (Walras, 1926).[103] The theory was formalised by Arrow and Debreu (1954), and later Debreu (1959) and Arrow and Hahn (1971), who specified mathematically the conditions for such an equilibrium to exist and this forms the basis of the Arrow-Debreu model. This is the underlying theory for all general equilibrium analysis.

In the model there are a number of utility maximising consumers who have a set of endowments i.e. own goods and factors of production. These consumers have preferences for a number of possible goods in the economy. These consumers are generally aggregated together and their maximised utility creates market demand functions for each of the goods. These market demands must satisfy Walras' law in that at the values of excess market demands (or market supply) must sum to zero.[104] There are also profit maximising producers with specific production functions who rent the factors of production and sell the end products to the consumers. There is therefore an equilibrium where market supply meets market demand for all goods at given prices and quantities of output. The three conditions for this to occur are market clearance, zero profit and income balance (Sue Wing, 2004). This is the standard market clearing, perfectly competitive model although nowadays many CGE models allow for deviations from these assumptions. It should also be noted that only relative, not absolute, prices are considered in general equilibrium models.

[103] See Shoven and Whalley (1992) for a detailed discussion of general equilibrium theory.
[104] For a simple textbook definition see Varian (2010) chp. 31

The general equilibrium models will often also incorporate a government sector which receives taxes from consumers and producers and redistribute them as subsidies or transfers while also purchasing goods. The government sector does not optimise but is important because it is often where the policy shock is implemented.

Figure 5.2: Circular flow of the economy



Source: Sue-Wing (2004)

It was the work of Scarf (1967a,b) and Scarf and Hansen (1973), by creating necessary algorithms, which helped transfer general equilibrium models from being purely theoretical in nature to actually being used as a practical analytical tool as this allowed solutions to be found to complex theoretical models. This work has been lauded as a significant moment in the development of CGE models (Arrow, 2005). Until this point it was mostly IO analysis developed by Leontief (1951) that was used extensively as a multisectoral tool in policy work. Also, the work of Johansen (1960) contributed significantly to furthering this area of research of turning theory into application by creating a CGE model for Norway for 1950 based upon general equilibrium theory which linearised the models's equations much in the same way as

IO analysis. These two approaches have been used as the basis to undertake further work and create the modern day CGE model. In the 1980s the users of Scarf-type model began to use SAMs as their dataset. Another significant factor in the advance and increasing use of CGE models is that over the past few decades the development of computer programmes has benefitted this type of modelling immensely and allowed previously theoretical concepts to be applied to many different policy issues by almost anyone who can access to a model which can be solved using such a computer programme. Standardised programming allows for code for CGE models to be easily shared by researchers who have the underlying knowledge to apply, run and interpret the models correctly.

Sue Wing (2004) demonstrates, by example, the link between general equilibrium theory and practical modelling. He derives a CGE model from Walrasian first principles, incorporates the dataset and calibrates the model and finally gives a practical example of a policy application.

Overall CGE models combine the theory of general equilibrium with real data to simulate equilibrium in a specific economy. They are often used as a tool to consider the overall welfare and distributional impacts of proposed policy implementation on the economy. Therefore they are used extensively by interested parties such as national governments, international institutions, consultancies and academics.

4.2 Model structure and form

In this section I will give an example of the details of a general CGE model and the various assumptions and issues involved in creating a model. As their features can differ substantially, there is no single standard CGE model which makes it difficult to describe and capture all possible considerations. However, I give a broad summary of the main points involved in CGE models without a detailed discussion of the merits of the application under specific circumstances. Whalley (1991) identifies the following as key issues in designing CGE models: model structure and database; functional form and parameter value choice; level of aggregation; solution methods;

approaches to evaluating policy, and uniqueness of the model's equilibrium. I will briefly discuss each of these consecutively.

The model structure is completely dependent upon what the purpose of the model is in turn i.e. what it is to be used for, as well as the availability of data. It consists of an accurate database of economy-wide data for a single year together with a system of equations for variables which describe the model equilibrium. The equations used in CGE models often have a neoclassical basis in that households maximise utility subject to a budget constraint while producers minimise their costs. From these it is possible to derive demand and supply functions for the economy. CGE models often have the characteristic of two factors of production (labour and capital) although it is possible to incorporate more.

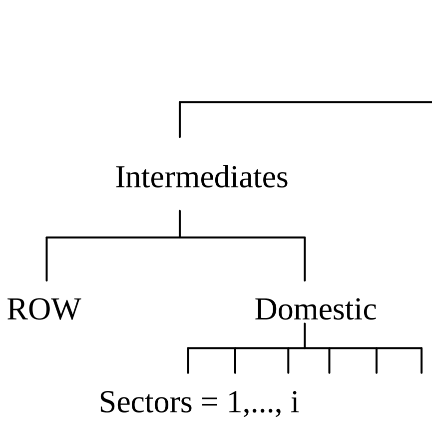
The benchmark database tends to be national accounts, usually an input-output table and other national income data presented as a social accounting matrix (SAM), as this gives accurate economy-wide data describing the flows of income and expenditure for a specific year between all sectors and individuals in the economy. The IO table describes all inter-industry transactions, normally 123 economic sectors in the UK tables published by the Office of National Statistics (ONS), in that specific year. It also identifies the contributions of labour and capital to each industry as well as the final demands of households, government, investment, imports and exports.

National accounts are then used to expand the IO table into a more detailed SAM by adding information on transfers between institutions e.g. household and government, so that all economic transfers are reported. Therefore all flows of income, expenditure and transfers in the economy during a given year are known. Government accounts allow attribution of public revenue and expenditure and trade accounts detail the apportioning of exports and imports. This dataset is assumed to be the long-run equilibrium of the economy in the model so choice of year for the database can be important to the final results. Households in the model are both consumers and owners of factors of production. It is also possible to disaggregate households into different types similar to what is done with the industries/goods. The likely form of household disaggregation would be into income brackets in order to consider the distributional impact of a policy although other approaches are possible (De Fence and Turner, 2010). Production technologies are often assumed to have constant returns to scale and there are no economic profits in long-run equilibrium. The data used as the benchmark must be consistent with national accounting identities and where this is not the case then adjustments must be made.

The choices of utility and production functions must be decided at an early stage too. These functional forms need to be consistent with the underlying theory and generally ‘well-behaved’, which allows for easy interpretation. Cobb-Douglas or Constant Elasticity of Substitution (CES) are the functional forms most commonly used. Leontief functional forms are also adopted where appropriate. The choice of functional form will determine the relationship between inputs in the model. Initially it may be beneficial to look at the same policy disturbance while comparing different functional forms. Choice of exogenous values for key parameter values such as elasticities of substitution must be decided upon either by direct estimation or from the relevant econometric literature. The CES function is more flexible than Cobb-Douglas, where the elasticity of substitution is required to be unity, and also Leontief, where elasticity of substitution is zero. However, CES functional forms are limited themselves in the fact that the elasticity of substitution is the same between all factors.

Nested production functions separate production into different levels where relationships between inputs at each level can differ. A simple example of this is given below in Figure 5.3. Here the produced gross output of a sector is a combination of intermediate inputs and value-added at the top of the hierarchy. Their relationship can be determined by one of the functional forms. The value-added component will itself be made up of a composite of capital and labour, where there will be a given degree of substitution between these components.

Figure 5.3: Example of a basic CGE Production structure

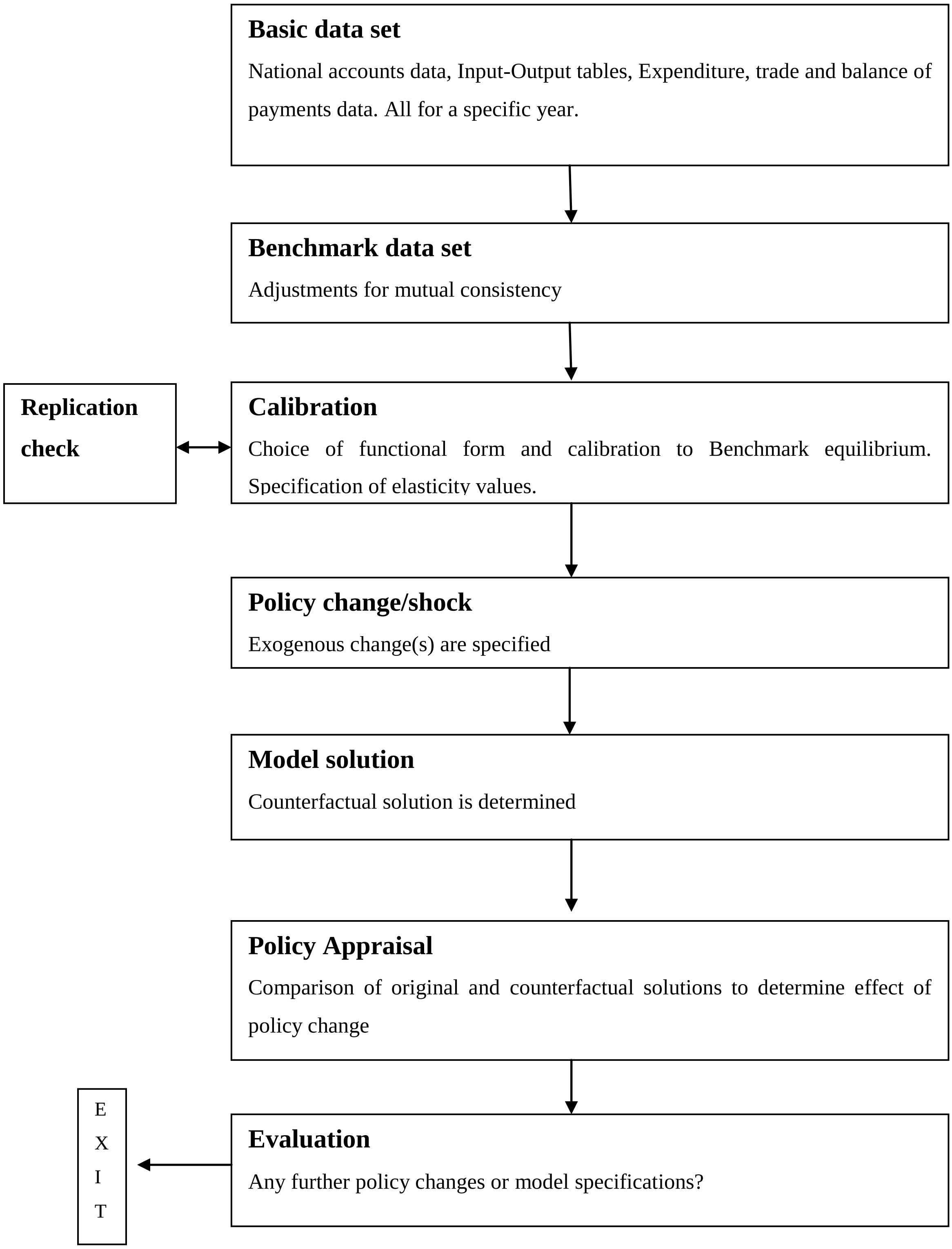


The level of aggregation of goods in the CGE model is an important consideration. Many Input-Output databases have several hundred separate sectors. Although this gives more detailed output, it may not be sensible to have so many sectors when implementing a CGE model in terms of practical calculation and interpreting results. For this reason a level of aggregation that trades-off ease of use against an adequate treatment of the main policy issue is appropriate.

Model closure is determined by specifying a number of the model variables as exogenous. The number of independent equations will limit to how many variables can be endogenous. Therefore, which of these variables are exogenous depends upon macroeconomic assumptions made for the economy in question. For instance, whether or not there is full employment must be decided and modellers may wish to relax this assumption somewhat to make the model more realistic in terms of market behaviour. Other labour market assumptions may also be made to this effect regarding wage rigidities or how flexibility of labour supply e.g. whether net migration in the economy is possible to increase/decrease labour supply. Treatment of savings and investment is also a key closure issue in a CGE model. Investment is often endogenous and determined as the difference between actual and desired capital stocks less any depreciation. Investment then can gradually update capital stocks between periods where possible in response to any policy shock. Finally, if supply is assumed to be completely passive then this will generate the same results as IO analysis in response to a demand disturbance.

How trade is incorporated in the model is important, depending on the model's purpose. Both international and interregional trade can be modelled within a single-region CGE model by treating the rest of the world as exogenous. Intermediate inputs as well as final goods may be imported and exported and therefore an elasticity of substitution between domestic and foreign goods must be established. The most common approach is to adopt the Armington (1969) assumption that differentiates goods by country. This means that a good is not the same when produced in another country. So for example textiles produced in the UK are not perfectly substitutable with textiles produced in China. This allows world prices for UK and Chinese textiles to differ and allows for both importing and exporting of this good. In a case with perfect competition but without the Armington assumption, then for a specific good, a country would not typically produce a good that it imports. The Armington assumption therefore means that producers will choose between domestic or foreign intermediate inputs, and consumers between domestic or foreign goods, depending on relative prices as well as the Armington elasticity of substitution. This ensures there is no extreme specialisation and shifts in production.

Figure 5.4: Overall CGE procedure



Source: Adapted from Greenaway *et al* (1993)

The model is then calibrated against the original data set. That is to say, a number of parameters will be set so that when run against the set of base year exogenous variables, the model reproduces the base year endogenous variables e.g. the base year data set. There is therefore an assumption that this calibration will be the original equilibrium against which all policy shocks or exogenous changes will be compared. A policy or exogenous change can then be simulated by varying the value of a specific parameter which is of interest to the relevant study and the model is then solved for a new set of price and production levels. The model incorporates changes in relative prices and the production and consumption functions allow for substitution in response to the relative price changes. A solution is then calculated for this new equilibrium post policy shock. This new counterfactual solution is then compared against the original benchmark equilibrium and the differences between the two allow the user to view the effect that the change has on the economy as shown in Figure 5.4. CGE models allow for comparison of macroeconomic variables such as employment and GDP as well as those variables of individual industries.

4.3 Strengths and weaknesses

It is worth discussing the strengths and weaknesses of CGE modelling that makes it a particularly useful tool for certain purposes but not helpful for others.

One of the most important features of CGE modelling is that it is based upon clear theoretical microfoundations, in that household and producers consumption and production behaviour is explicitly modelled (Greenaway *et al*, 1993). This underlying economic theory therefore allows policy makers to consider and understand any micro-level changes which may be of interest. There is complete transparency concerning these behavioural assumptions which can make analysis and interpretation of results easier. Where results seem unlikely then this transparency allows for modellers to understand why they are occurring. Also, the model structure and functional forms can be changed and results from simulations with different model specifications may be compared to determine the extent to which different assumptions can affect outcomes (Greenaway *et al*, 1993).

In terms of the policy change, it is possible within CGE models to evaluate non-marginal changes and also introduce a number of simultaneous shocks to simulate a 'policy package' by changing more than one exogenous variable. However, interpreting the results of such policy packages may be difficult unless compared against the results of each individual policy change. CGE models are particularly flexible in that they can be easily modified to simulate various different underlying assumptions. For instance, elasticity parameters can be changed, the model run again and the results of these compared. This ease of use and flexibility can make CGE appealing to modellers.

CGE models are multisectoral and this feature allows model results to capture the interdependencies and feedbacks between all industries and transactors within the economy. These interdependencies can be complex and therefore CGEs go beyond what most other models can do. For example, partial equilibrium models assume the constraint that 'all other things are equal' in their results. This multisectoral aspect allows not only for aggregate results of a policy shock (efficiency) but also the impact on individual sectors, which may well differ from the aggregate trend (equity). Therefore it is possible to view which sectors are positively affected and which are negatively affected by the disturbance e.g. the distributional effects. Also, if there is a particular sector which is of interest then within a CGE model it is relatively straightforward to separately identify this sector within the model, assuming the data are available, and then focus on the results for that particular sector. This is relevant in instances where the shock might apply to only one or a small group of sectors.

A major benefit of CGE models is that, unlike other multisector models such as IO, they are able simultaneously to incorporate both demand-side and supply-side analysis. CGE models often use IO tables to construct their benchmark database, but by explicitly identifying price-sensitive production and consumption behaviour and the existence of fixed inputs in the model, then it is possible to go beyond the limiting IO analysis which assumes that the supply-side is completely passive. CGE models can therefore also deal with supply-side shocks which are often the most important from a policy perspective.

CGE models do have particular weaknesses that can be identified. CGE models can incorporate any functional forms but there is computational difficulty in doing so with certain functional forms which are more complicated. For example, a perfectly competitive model cannot incorporate increasing returns. Therefore simple, well-behaved functional forms tend to be employed such as Constant Elasticity of Substitution (CES) or Cobb-Douglas. Therefore a drawback of CGE models is that there is a lack of choice of the underlying functional forms and this may be restrictive to outcomes.[105] Choices tend to reflect the functions that have performed well during previous econometric studies (Greenaway *et al*, 1993) but may not necessarily be an accurate representation of agent's behaviour. Therefore it is not possible to say exactly which functional form is correct for a specific model.

Conducting a sensitivity analysis around the functional forms and key parameters may help overcome this weakness by showing alternative results and making transparent that certain assumptions may be crucial to model results. Another weakness is that the model is calibrated against a baseline year which is taken to be an equilibrium solution. This assumption of equilibrium may be misleading especially where data particular to that year may differ from most other years. For instance, if it was a particularly cold year then this may over estimate spending on heating and electricity within the economy or the base year may be during a recession. Also this baseline dataset may be aggregated to such a degree that it no longer provides detail on important underlying relationships.

Parameterisation of the functional forms can be an issue where parameters are taken from secondary sources, econometric studies or the modeller's own judgement. The choice of these parameters, such as elasticities of substitution, is crucial to the model results but these parameters may be unsuitable for the particular economy and/or year. To overcome this weakness many CGE modellers will undertake sensitivity

[105] See McKitrick (1998) for a discussion of restrictions of functional forms for CGE models

analysis around the parameter values. The assumption of uniqueness of an individual solution is also considered a weakness of CGE models. The model assumes that only one equilibrium solution is possible to calculate but in practice it is possible that multiple eqilibria exist. However, Greenaway *et al* (1993) state that there are no reported cases of multiple equlibria and that the 'well-behaved' functional forms may make it unlikely for them to exist.

Closure of the model is also considered a problematic aspect of CGE models. The number of equations limits the number of endogenous variables that can be solved for and therefore the model must be 'closed' to specify which variables are endogenous and which are exogenous, although this is true of all types of modelling in some respect. Closure is often done through imposing a balanced budget, balanced trade or a savings-investment identity (Greenaway *et al*, 2003) and this assumption will affect results. Choice of closure will depend upon the nature of the economy being modelled but there may not be an obvious choice which is realistic.

Including dynamics and expectations within a CGE model is far from straightforward. Until recently CGE models tended to be comparative static in nature. However, more and more dynamic models have been developed, although the degree of dynamism can vary. The dynamics are often recursive in nature and so in each single period an equilibrium occurs where consumers and producers optimise and each of these static equilibria are linked through stock-flow relationships. For instance, flows of investment and migration in previous periods will update the stock of capital and population in the next period. Agents are generally assumed to be myopic in CGE models although some recent models incorporate forward looking dynamics such as Lecca *et al* (2011a).

Finally, monetary sectors tend to be ignored within CGE models because production functions are homogenous of degree zero with respect to prices and so only relative prices are a concern within the model. The extent to which this is accurate can be disputed as by disregarding the financial side of the economy there is no concern with nominal price changes and the impacts of financial markets. Some CGE models do incorporate financial markets but usually in a simple way.

An often cited criticism of CGE models is that the simulations are a 'black box' in that given the many assumptions there is no clear causality between them and the results because of the complex model relationships. However, by employing sensitivity analysis around many of the assumptions and by altering model parameters as necessary it is possible to begin to distinguish the underlying causalities. It is simply necessary that assumptions, equations and values are explicitly stated in all work.

Table 5.2: Evaluation of CGE modelling: Strengths and weaknesses

Strengths	Weaknesses
Benefits of solid microfoundations	Simplicity of functional forms
Ability to include explicit welfare functions	Sensitivity to closure rules
Distributional aspects	Inter-temporal substitution and dynamics
Facility for evaluating 2nd best situations	Inability to test model structure
Capacity for disaggregation to sub-structure	Parameterisation and calibration
Ability to model non-marginal changes	Derivation of Benchmark data set
Coherent structure for evaluating "complex" problems	Equilibrium characteristic of benchmark selection
Facility for simulation of alternatives	Expectations
Framework for evauluating interdependencies and feedbacks	Primitive or non-existent monetary sectors
Ability to model instrument constraints	Uniqueness of solution
Confronts modeller with "The problem"	

Adapted from Chapter 4 of Greenaway *et al* (1993)

4.4 Use in policy analyses

CGE models are often used as a tool to analyse policy options because of their ability to consider the complex interactions of the entire economy. Once the model has been calibrated the baseline equilibrium can be reproduced. Then the policy change is implemented in the model and a new equilibrium is calculated. These two equilibria, the baseline and the counterfactual, are then compared to see the effects that the policy has on key variables in the economy. Due to the inter-industry element of the model, it is possible to consider both aggregate welfare and potential distributional effects the policy may have. Often policy makers are concerned equally about distributional effects of a policy as well as its overall effect. Therefore CGE models can be extremely useful for policy appraisals. Policy makers who have an interest in specific industries as well as overall effects can therefore use CGE models for both goals. Obviously CGE results, like all economic modelling, should be considered as giving only an indication of the possible outcomes.

For the reasons detailed above, CGE models are increasingly used as a tool in policy analysis. They have been applied to a wide range of areas such as international trade, taxation, population, welfare, regional policy and higher education.[106] Recently CGE models have been applied to environmental and energy issues and in particular the reduction of carbon emissions to tackle climate change. Since CGE models incorporate effects across the entire economy, as well as being multisectoral, this makes them a valuable tool for considering environmental and pollution issues at an economy-wide level. Changes in output and production in one sector will not only have direct effects on pollution within that sector but these production changes will also impact economy-wide on other sectors and household consumption through multiplier effects. Therefore, by linking emissions to production, it is possible to utilise CGE models to determine the effects of possible relevant policy changes, or shocks to the economy, on the environment. This environmental impact is becoming a greater concern for policy makers and CGE models can be useful where this impact may have general equilibrium effects.

The environmental CGE models have tended to either be global (or multi-country) models or they have been single-nation (or regional) models. Given the focus of this thesis on UK climate change policy I only consider national models. These national

[106] See Devarajan and Robinson (2002) for a discussion of how CGE models have been applied to policy analysis.

or regional models invoke the “small open economy” assumption where the rest of the world is taken to be exogenous. Only the nation of interest is modelled explicitly and although trade allows interaction with other countries, it is assumed that the nation is so small, in comparison to the rest of the world, as to exert an inconsequential impact on it. In terms of modelling the climate change problem, this “small open economy” assumption appears like a valid assumption to make because the worldwide environmental impact of an individual nation’s economic activity is taken to be minimal. This would seem appropriate for small nations but perhaps less so for larger countries like China and the USA. It is therefore not possible to view and incorporate the global benefits of mitigation by a small nation in the simulations. The environmental CGE model therefore is used to consider the nation’s economic costs and benefits of achieving its own emission reductions.

In terms of environmental CGE modelling with regards to climate change there are two important aspects. Firstly, how energy use is modelled is a key assumption as energy plays such a large role in pollution activity. Several taxes aimed at reducing emissions are in fact energy taxes which will change the supply and demand of energy e.g. climate change levy. Bergman (1988) states that the elasticity of substitution between energy and other factors of production is significant in determining the effects of environmental policies aimed at reducing emissions. Therefore how energy is incorporated into the production structure of the model must be decided upon in any environmental CGE model and this tends to be the main area of debate for many environmental CGEs. Various different assumptions can be made about the nested production functions as to whether energy can be directly substituted with other inputs. What types of energy are modelled must be decided too. These will tend to be coal, gas, oil and electricity, the first three of which are all fossil fuels. How electricity is produced is very important and substitution between fossil-fuel and renewables in electricity generation should be modelled.

Secondly, how pollutants are modelled is extremely important as it is these emissions which cause climate change that most nations are interested in decreasing. The two main approaches are to either link emissions to outputs or inputs. The most basic method is to link the polluting gas (often CO_2 for climate change) to economic activity by creating linear emissions-output coefficients. These coefficients identify the amount of emissions per unit of output for each economic sector. However, this technique can be limiting in the sense that it does not allow for the effects of technology changes and substitution within sectors, as emissions are simply proportional to output. Therefore, when linking emissions to output, the only method of reducing the emissions of a sector is to reduce its production (Beghin *et al*, 1995). The easiest way to reduce emissions may simply be to decrease production; however, this is not optimal as it entails a lower GDP and is therefore at odds with the government objective of growth. This can be thought of in another way. This method of linking emissions to output only allows for technical substitution *between* sectors but not *within* sectors. In reality there are two ways in which emissions can be lowered *within* a sector; either through changes in the input mix e.g. moving to cleaner fuels, or by developing cleaner technologies regardless of fuel type e.g. catalytic convertors. In a CGE model it is possible capture changes in the input mix of sectors by linking emissions to inputs with fixed input-emissions coefficients.

This has become the standard method in environmental CGE models. Dessus *et al* (1994) explored the consideration that the variation in emissions can mostly be attributed to changes in inputs. These coefficients tend to be calculated using specific emissions factors for fuel use because there is a direct technical relationship between the amount of a fuel used in production and emissions associated with that use. There may be slight differences across sectors in terms of technology or type of combustion but in general the amount of emissions created is directly related to fossil fuels used, especially for CO_2 where fuels have associated carbon content. However, some sectors may be inherently polluting regardless of, or in addition to, fuel combustion and therefore it may be appropriate to link emissions to output in such cases because emissions can only be reduced through reduced output.[107] There is not currently a sophisticated means to model these other gases using this type of model.

[107] This is particularly appropriate to non-CO2 emissions which are more dependent on technology and methods of combustion.

Beauséjour *et al* (1995) contend that emissions may best be modelled through a combination both input and output relationships. They explain that "Emissions of air pollutants in the model arise from the combustion of fossil fuels in intermediate production and in final demand, and from some industrial processes that are themselves inherently polluting". In this instance it is possible to reduce sectoral emissions in two ways. Firstly, emissions can be reduced by changing inputs used in production i.e. substituting from fossil fuels to renewables, which will imply changing the composition of total output. Secondly, emissions reduction can occur by reducing output levels; this will reduce the overall level of total output. The second option is only possible in those sectors that are inherently emissions intensive and therefore emissions are an essential by-product of production.

It would also be possible to reduce emissions by making use of emissions abatement technologies where they are available. These can be modelled as a specific capital good for each industry (Beauséjour *et al*, 1995). However, with regards to CO_2, abatement technologies of this kind, such as Carbon Capture and Storage (CCS), are not yet close to market and are therefore not an economically viable option. Therefore models tend not to include this option of abatement technologies for carbon dioxide.

5. REVIEW OF NATIONAL CGE MODELS WITH A CARBON TAX

In this section I provide a review of environmental CGE analysis where a carbon tax has been applied and in particular focus on national models although a few regional models are mentioned. Attempting to determine the potential effects of introducing a carbon tax, either globally or to a specific economy, has become an increasingly important issue for policy makers over the last decade. General equilibrium models have frequently been used for this purpose because they are flexible, wide-ranging and robust enough to tackle such a question. There are CGE models which incorporate carbon taxes at both inter-regional and national levels. In this section I give an overview of most relevant previous applications of CGE modelling to climate change at national levels, given that the CGE model is a national UK model, with particular reference to the double dividend. The list is by no means exhaustive but is intended to give an overview of motivating work and issues.

5.1 National/regional CGE models without recycling

Agostini *et al* (1992) models the effects of a carbon tax on Europe, which is treated as a single nation with four economic sectors: Industry, Power Plant, Residential, and Transport. Their focus is on combustion of fossil fuels as being responsible for carbon emissions to consider the effects of carbon taxation on energy saving and inter-fuel substitution. The industrial and electricity sectors model coal, natural gas and fuel oil; in the residential sector gas oil and natural gas are modelled; and for transport both gasoline and diesel are used. They employ a tax for each fuel, which varies depending upon the carbon content. There are low $5/ton C, medium $50 ton/C and high $100 ton/C tax rates which are compared against a baseline ‘no tax’ scenario where the simulation period is 1989-94. The baseline simulation is growing. Their results show the effects of the various levels of carbon tax on consumption, emissions and fiscal revenue. Consumption of coal in the industrial and electricity sectors decreases for each tax level and is compensated for by increases in gas consumption and occasionally small increases in oil. The residential sector sees an energy saving effect and in transport there is a switch from gasoil to gasoline. In terms of reducing emissions, the taxes are most prominent for the electricity sector which registers a reduction in emissions compared to its 1988 level, although overall emissions for the economy are growing for all carbon tax rates when compared against their 1988 level. The high and medium taxes do reduce overall emissions growth when compared with the baseline scenario. Fiscal revenue is high in industry and electricity but small in residential and transport. No detailed discussion is given as to why these results occur.

Scrimgeour *et al* (2005) consider how different environmental taxes can be employed to reduce national carbon emissions in New Zealand to help the government achieve its Kyoto Protocol target. Using an energy version of the ORANI CGE model (Dixon *et al*, 1982) they consider and compare the impact of energy, carbon and petroleum taxes (the latter of which I do not report here) to work out which is the optimal instrument for the New Zealand economy. The model allows for inter-fuel substitution and also substitution between capital and energy. Investment is modelled so that its initial value is proportional to the size of investment at the end of the simulation period. Each tax is set on coal, gas, oil and petroleum products to collect 0.6% of GDP in the base case. The carbon tax reduces CO_2 emissions by 18% and energy use by 14% while the energy tax reduces emissions by 16% and energy use by 13%. In terms of macroeconomic effects the energy and carbon tax are similar with the carbon tax having a slightly larger impact. The carbon tax (energy tax) reduces real household consumption by 10% (9%). Overall a carbon tax is the most effective of the environmental taxes in reducing emissions but in most situations the carbon tax also has the largest negative macroeconomic effect on reducing GDP, household consumption, exports and investment, although only marginally more than the energy tax. The authors believe the drop in macroeconomic variables is caused by a fall in the capital stock causing lower investment. These results may be determined by the model closure assumptions. Although it is not particularly a like-for-like comparison of energy and carbon taxes, these results do give an insight into the likely impacts of different types of taxes on the New Zealand economy.

Wissema and Dellink (2007) also model the different policy instruments to reduce emissions; they consider the impact of carbon and energy taxes on the Irish economy. The model is a static CGE model with a small open economy assumption. There are twenty six commodities, seven of which are energy. Energy combines with capital in the nested production structure which then joins with labour to form a value-added composite. They attempt to reduce CO_2 emissions related to energy in Ireland by 25.8% compared to 1998 levels using two instruments. They compare the use of a carbon tax which is based on the emissions factor of each energy source against a uniform energy tax where all energy is taxed evenly. Seven different simulations of varying *ad valorem* tax levels are carried out for each instrument. These seven simulations are taxes of 0, 5, 10, 15, 20, 25 and 30 Euros. They find that the target reduction of 25.8% is possible using a carbon tax of between €10-15 per tonne of CO_2. The carbon tax achieves higher emissions reductions through larger switching from coal and peat towards renewables than the energy tax does. They also find that although fuel switching is an important part of making the target, assumptions about producer's ability to substitute between energy and non-energy inputs are also crucial in achieving the emissions target.

5.2 National/regional CGE models with recycling

Welsch (1996) looks at the effects of recycling a carbon tax through the labour market using a computable general equilibrium model of the European Community and shows that achieving a double dividend is possible under certain conditions. The model is two-region with 13 sectors, five of which are energy sectors (four fossil-fuels and electricity). Welsch stresses, when modelling, that the effect of employment of reduced labour costs from recycling depends critically on assumptions about the labour market. In particular how substitutable are labour and energy. In this model energy enters the production structure in an energy-capital-labour composite which is Leontief with non-energy intermediate inputs and an intermediate energy to produce sectoral output. Below EKL aggregate there is an energy-capital composite which substitutes with labour via CES. All other substitution in the model is CES. Below that capital and energy substitute and energy is a composite of fossil fuels and electricity. The fossil fuels composite contains hard coal, brown coal, oil and gas. The elasticity among fossil fuels is generally greater than between fossil fuels and electricity. Also, assumptions about how wage claims react to increased labour demand will affect results. Where the unemployment rate is reduced then the increased number of workers gives a greater bargaining power for wages.

The model is run for two different elasticities of the wage rate with respect to the employment rate of 0.4 and 1.4 respectively.[108] The model runs from 1996 to 2020 and the tax, based upon European Commission proposals, starts at 3 dollars per barrel of oil in 1996 increasing by one dollar each year until 2006 and by half a

[108] Note that the elasticity is with respect to the employment rate, not the unemployment rate.

dollar each year after. Revenues are recycled simply through wage subsidisation. A double dividend (of increased employment and GDP) is achieved for both recycling scenarios but larger increases in economic conditions are associated with the lower wage elasticity case. GDP and employment have increased by 1.85% and 2.78% after 24 periods for the low elasticity case but only 0.2% and 0.71% for the high elasticity case. This occurs because when wages are more elastic with respect to the employment rate then more of the recycled revenue is captured by higher consumer wage claims. Therefore producer wages are not reduced as much as in the less elastic case and so labour demand is not increased and GDP approaches zero in the long run. Emissions are reduced in both wage elasticity scenarios, but more so for the higher elasticity because the larger increase in GDP from the lower elasticity case is associated with a higher level of emissions. He concludes that CO_2 reductions and increased employment can be achieved by a carbon tax provided that increased employment from reduced labour costs are not offset by increased wage claims, and that in this instance also GDP increases.

Zhang (1998) analyses a dynamic CGE model of China. There are 10 economic sectors, four of which are energy. In the production function the four energy inputs combine to form an energy composite (Cobb-Douglas) which then combines with a labour-capital composite (Cobb-Douglas) in a factor composite using a CES function. The factor composite then combines, in a Leontief function, with intermediate inputs to generate gross output for each sector. A growing baseline scenario is developed between 1990 and 2010. In this scenario GNP grows at an average annual rate of 8.34% for the first ten years and at 7.55% for the latter ten years. Carbon emissions grow at 4.4% annually for the first ten years and at 4.8% for the latter ten years. Against this baseline two main emissions reduction scenarios are simulated. In Scenario 1 a reduction in emissions in 2000 and 2010 is imposed of 20% from the baseline scenario emissions levels. Scenario 2 is 30% reduction over the same period. In both cases the revenues are not recycled. These emissions reductions are achieved by fuel-specific carbon taxes on coal, gas, oil and electricity.

The Scenario 1 (2) emissions targets is achieved at a rate of 205 (400) yuan per tonne of carbon (tC) through trial and error to gain the appropriate solution. Both Scenarios 1 and 2 see a fall in GNP of -1.52% and -2.76% respectively, compared to the baseline. He also measures welfare using Hicksian equivalent variation which sees a fall of -1.17% and -2.97% under both scenarios respectively. Exports are significantly affected by achieving these carbon targets which fall by -5.38% and -7.45%. These are driven by a reduction in production in some sectors. All economic sectors reduce their production under both scenarios, especially energy-intensive ones, with the only exception being the service industry which is increased by 1.7% and 5.5% in Scenarios 1 and 2 respectively. This increase in the service sector occurs because as production falls in other sectors, capital and labour, which are fixed, move from those sectors to the service industry which uses only a small proportion of factors affected by the tax. Zhang (1998) then goes on to recycle the revenues by reducing indirect taxes across the board by 5% (Scenarios 1a and 2a) and 10% (scenarios 1b and 2b). As expected the revenue recycling lessens the emissions reduction as the extra revenue used to reduce taxes then increases private consumption and international competitiveness in comparison with the no-recycling scenarios which leads to greater production and therefore emissions. The drop in GNP is slightly offset by this increased consumption and production. Scenario 1b actually achieves a double dividend of reduced emissions and welfare gain (when measured a Hicksian equivalent variation).

Manresa and Sancho (2005) model the Spanish economy based on a 1990 SAM to consider whether a double dividend is possible through reducing labour taxes from a revenue neutral “ecotax” on all energy goods. They firstly run a ‘*rigid*’ model simulation where there is no substitution between factors of production and where unemployment is kept fixed and the labour supply is inelastic. Therefore changes depend on consumption decisions and the real wage adjusts to clear the labour market. Then there is a ‘*flexible*’ model where factor demands can adjust and the unemployment is endogenous. For both the rigid and flexible models they run two scenarios: one with no recycling and one with labour tax compensation that imposes revenue neutrality. Three taxes are applied for both of these scenarios: (a) a 10%

'ecotax', (b) a 15% increase in petrol tax, and (c) both (a) and (b). For the flexible model with tax recycling, there is one simulation with an elasticity coefficient measuring the sensitivity of the wage rate to unemployment equal to 1.25 and another extreme case in which it is infinite and therefore real wage is fixed but unemployment is perfectly flexible. Emissions are reduced in all scenarios. In the *rigid* model unemployment cannot fluctuate so an employment double dividend is *a priori* not possible. Where all taxes are applied in the *flexible* model and there is no recycling unemployment rises slightly, compared to the base situation due to both the output and substitution effects. However, where labour taxes are reduced the unemployment rate decreases and so a double dividend is achieved. They find that it is possible to simultaneously have a reduction in CO_2 together with improved levels of employment. Therefore they believe that flexibility in the labour market improves the chances of a double dividend.

André *et al* (2005) consider the specific region of Andalucía in Spain and whether a double dividend is possible when a revenue neutral CO_2 tax is imposed (they also consider a SO_2 tax but we ignore these results here) and revenues can be recycled by reducing either income tax or payroll tax. The income tax is paid by consumers while the payroll tax is paid by producers. Also, the authors believe that given Andalucía's high level of unemployment, then there are probably major tax distortions in the labour market and so reductions in labour market taxes would be beneficial. A SAM of the region for 1990 is used to create a CGE model. There are six tax levels of 0.5, 1, 1.5, 2, 2.5 and 3 Euros paid per tonne of emissions so the sectors that emit more carbon dioxide will pay higher taxes. Emissions fall for all tax levels in both recycling cases but always more so when revenues are recycled through reductions in income tax than in payroll tax. This could be driven by the fact that for all tax levels, the payroll tax recycling increases disposable income more than the income tax recycling and therefore this increase in economic activity is associated with more emissions. They conclude that for income tax recycling "the distorting effects of the environmental tax (which depress consumption and economic activity) overpower the incentive effect of reducing IT". However, a double dividend, in the form of an increase in GDP over the base-year level, is only achieved through recycling by payroll tax. For instance, a tax rate of 2 Euros reduces real GDP by 0.86% under income tax recycling but increases real GDP by 0.08% under payroll tax recycling. An employment double dividend also arises under payroll recycling as the employment rate increases in all scenarios but this is not the case for recycling through income tax. The authors believe that these results occur because payroll tax is strongly distorting compared to the environmental tax while income tax is not.

Takeda (2007) considers how a double dividend may be achieved through carbon regulations in Japan. A multisector dynamic CGE model is used where eight of the twenty-seven sectors produce carbon emissions, using data for Japan in 1995 as the benchmark year. Growth is introduced to the model through labour and technology growth rates. A carbon tax is set by the government to achieve a specific target emissions level and is imposed on emission sources on the basis of their carbon content. Four different emissions targets are considered of various degrees of strictness. The most stringent requires emissions stabilised at their benchmark year. The government budget is revenue-neutral and so revenues are recycled through five different possible methods: labour income tax, capital income tax, consumption tax, capital tax, and labour tax. These are compared against the case where revenues are returned to households in a lump-sum manner. Takeda looks at the change in lifetime utility from the baseline case. As expected the lump-sum recycling reduces lifetime utility the most for all four emissions targets. All other recycling methods reduce lifetime utility as well i.e. a weak double dividend is achieved in all cases, but by a smaller extent, except for the capital tax. Reductions in the capital tax by recycling carbon taxes in Japan actually increase lifetime utility for all emissions targets i.e. a strong dividend is achieved. Takeda believes that this result occurs because capital taxes are more distrortionary than labour and consumption taxes in Japan.

Palatnik and Shechter (2008) create the first economy-environment static CGE model for Israel to determine the economy-wide impacts of meeting (hypothetical) Kyoto reductions targets. They use a SAM for 1995 as the database and treat Israel as a small open economy with 18 sectors (4 of which are energy). Capital combines with energy first in the production structure, then this composite combines with labour and finally the KLE composite combines with materials. They model the effects of revenue-neutral *ad valorem* carbon taxes levied on energy sources; the tax rate is proportional to their emission factor. They carry out two scenarios for a range of four different tax rates. In Scenario 1 aggregate labour and capital are fixed exogenously and these markets are cleared by endogenous factor prices. In Scenario 2 they extend the model to make labour supply endogenous. Here, the labour supply depends upon relative changes in the wage rate where there is a negative relationship between the real wage rate and the unemployment rate. For the first scenario they assume revenues are recycled through reducing all pre-existing taxes equally. In the second scenario all revenue is recycled through a reduction in income tax. It is not clear why they do not use only one method of recycling across both scenarios because undertaking different recycling methods makes their results incomparable.

They find that there is no double dividend for all tax rates in the first scenario (looking at welfare and GDP only, they do not consider employment in Scenario 1 as labour is fixed and so an increase in employment is impossible). In this instance the lowest tax of $4.6 per tonne of CO_2 reduces emissions by 9% with a 0.31% reduction in GDP. The highest tax rate of $18.17 per tonne of CO_2 reduces emissions by around 25% and causes a fall in GDP of 0.96%. They then redo Scenario 1 for an alternative production structure where labour and capital combine first and then join energy in the next nest. In this instance emission reductions from the carbon tax are not as great but welfare and GDP do not fall as far as there is less ability to substitute between energy and labour. GDP falls by 0.12% with the lowest tax and 0.49% with the highest tax. These results will depend on the elastcicities of substitution in the original case (0.65 between capital and energy and then 0.85 between KE and labour) compared to the new production structure (0.5 between labour and capital and then 0.5 between LK and energy) This reveals that assumptions about the rate of substitution between labour and energy are important to model outcomes. In the Scenario 2 labour supply is made endogenous through an equation stipulates a negative relationship between real wage and the unemployment rate (which has a 5% minimum rate). They also decide to keep the alternative production structure with an elasticity of substitution of 0.25 between labour-capital composite and energy where labour and capital below substitute at 0.5. Again this makes comparisons difficult except with the results for the same production structure in Scenario 1. Under the assumptions of Scenario 2 emissions do not fall as greatly for all tax rates, this is due to the increased consumption from the recycled revenue. GDP still reduces from the Benchmark but not by as much, only 0.08% (0.45%) as opposed to 0.12% (0.49%) in Scenario 1 for lowest (highest) tax rate. This highlights the importance of assumptions regarding the labour market structure. An employment double dividend is achieved however with endogenous labour supply in Scenario 2. The author does not explain how this is possible when using a static CGE model.

Fraser and Waschik (2010) use a static CGE model for Australia and the UK to consider the double dividend hypothesis. The model is version 7 of the GTAP model where production taxes are levied on energy goods (coal, oil, gas, petrol and electricity). They assume that both are small open economies and there is revenue neutrality where recycle of revenues is through reductions in either consumption taxes or income tax. Production is modelled with use of nested CES functions. There is also an endogenous labour supply which they expect to be important in determining the extent of a double dividend. Incorporating work by Bento and Jacobsen (2007) they extend previous models to incorporate a fixed-factor in the production of polluting goods and other sectors by assuming land, natural resources and a share of capital are specific factors of production. Land is a specific factor for agricultural products. Natural resources are fixed for forestry, minerals and the energy industries of coal, gas and oil. Capital is assumed to be partially fixed for all production sectors and three different simulations are run to reflect this ranging from 50% of capital being fixed in the short-run, 25% in medium run and 0% in the long-run where there will be perfect capital mobility.

Recycling through reductions in consumption taxes yields a double dividend in Australia but reductions in income taxes does not. Therefore they find that the way in which revenue is recycled will influence whether there is a double dividend. They find no evidence of a double dividend in the UK regardless of recycling method. In terms of fixed factors these introduce Ricardian rents which have the overall effect of reducing the *tax interaction* effect and increasing the *revenue recycling* effect to make a double dividend more probable. The intuition here is that with a larger share of capital, output elasticity is less and therefore a greater tax levy is required to reduce emissions to target. This tax levy raises more revenue which allows for a greater reduction in the original distortionary consumption or income tax. It is believed the differences between Australia and the UK arise because energy sectors are a much smaller share of total production in the UK and so less revenue is received here.

Bor and Huang (2010) ask whether a double dividend is possible with energy taxation for a CGE model of Taiwan. They model energy taxes applied to nine different fossil fuels for each year between 2009 and 2018 which were proposed in Taiwan's Energy Tax Bill in 2007. These taxes are increasing each year. Six different scenarios are then simulated. In the first basic scenario the taxes are implemented but not recycled. In the second and third scenarios the tax revenues are recycled through reducing individual income tax and business income tax, respectively. The fourth scenario splits the recycling equally between individual and business income taxes. In the fifth and sixth scenarios fiscal policies are introduced. Scenario 5 splits the recycling with a third going to individual income tax, a third to business income tax and a third to subsidise public transport. Scenario 6 gives a quarter to the same areas as Scenario 5 but with an added quarter to R&D development.

Their results show that although emissions are reduced under all six scenarios, there is only a double dividend, of increased GDP (but not employment), under Scenarios 2, 3 and 4. Scenario 1 sees a reduction in GDP of -3.97% in 2018 due mostly to worsened trade condition and reduced domestic demand. However, for a reduction in individual income tax (Scenario 2) this leads to larger household income and therefore increases consumption and investment. This growth outweighs the reduction in demand in the first scenario. Scenario 2 has the greatest effect on GDP of all scenarios increasing around 0.5% by 2018. Employment increases in Scenario 2 up until 2017 at which point it becomes negative. The reduction in business income tax (Scenario 3) also achieves increased GDP by lowering costs of production and encouraging investment but this is not as strong as the individual income tax effect. In this case overall employment falls by around 0.5% in the long run. Scenario 4 has similar impacts to 2 and 3 as the results lie in between these two and achieves the second best overall effect on GDP and employment. Scenario 5 sees a double dividend of reduced emissions and increased GDP for several years but GDP becomes negative in 2017 and 2018 under this simulation. This is because there is less revenue going to reduce individual and business income taxes and also public transport subsidisation does not greatly affect the economy. Under Scenario 6 there is no double dividend achieved throughout the entire tax period. Here only half the revenue reduces income taxes while the other half is spent on subsidies. There is substantially less consumption and investment under this case.

Sancho (2010) simulates a carbon tax for Catalonia in Spain for 2001 and updates the previous work of Manresa and Sancho (2005) by introducing CES functions at three levels of the production function. First, Armington substitution is allowed where domestic and imported goods combine to make gross output. Secondly, domestic output is made from two types of intermediate goods and a composite of primary factors. CES substitution between primary factors (labour and capital) is introduced. Thirdly, the input-output intermediate matrix is split between energy and non-energy goods. The non-energy goods sub-matrix has fixed coefficients while the energy sub-matrix uses CES technical coefficients between the five different energy types. The baseline scenario is where no substitution is allowed between any of the above CES functions. Then substitution at each nest is allowed individually and results are given in each case. Finally a simulation is undertaken where all substitution is allowed. Two separate tax bundles are considered: a 10% tax on energy goods and a 15% increase in petrol tax, and another where these rates are doubled to a 20% energy tax and 30% petrol tax increase. A third version is run where taxes are 10% and 15% but all elastcities of substitution are doubled. Revenues are recycled through reductions in payroll taxes. The model is static and allows for labour market flexibility through variations in the level of unemployment.

Sancho (2010) finds that the most critical elasticity for achieving a double dividend is the substitution between capital and labour. Only when these primary factors can substitute is there a reduction in emissions combined with a welfare improvement and a reduction in unemployment, a so-called “triple dividend” in this paper. This result occurs for both tax bundles where only capital and labour can substitute. The other simulations of ‘no substitution’, ‘Armington substitution’ and ‘energy inputs’ substitution do not find a “triple” dividend is possible for any tax bundle and in these cases the new energy tax exacerbates the pre-existing tax distortions. When all three CES substitutions are allowed together, a double dividend is achieved but to a lesser extent than the primary factors substitution simulation. Emissions reduce in all simulations as the increased cost of energy and energy-intesnive goods lead to lower consumption of them but Sancho finds that the elasticity of substitution among energy inputs is most important to reduce emissions as it is the most direct in allowing movement away from energy-intensive goods. However, doubling the tax rates, to 20% and 30%, does not lead to a doubling of emissions reductions suggesting diminishing returns of tax policy. When the elasticity of substitution for capital and labour is doubled (for the first tax bundle) then the welfare improvement is more than doubled. However, in this case emissions do not fall as much as in the lower elasticity case due to increased production levels. When the Armington elasticity is doubled then welfare does not fall as much and emissions are reduced by more than the low elasticity case. Where the energy inputs elasticity is doubled then emissions are reduced by considerably more but greater welfare losses occur.

The varying results found throughout these models and applications will be affected by several factors. A summary of the papers discussed here are listed in Table 5.3 in Appendix F. In particular the base year database will influence outcomes as this is the assumed equilibrium of the economy. Assumptions about production and labour market structures, macro-closures and parameter values will greatly affect results and some papers discuss these assumptions more clearly than others. It is therefore important that my analysis considers the impact of sensitivity analysis around such assumptions. The method of recycling carbon tax revenues appears to be crucial in whether a double dividend outcome is likely for an economy. Therefore all of these considerations must be addressed in my model simulations, which while expanding upon this earlier work provides a more thorough analysis of the sectoral aggregation, through the work of chapters 3 and 4, to ensure that the relevant technological, environmental and policy considerations are at the forefront of the model simulations.

6. THE UKENVI CGE MODEL

In this section I describe the modelling framework which I use to simulate a carbon tax on the UK economy. With the previous sections in mind I employ a version of the UKENVI model which has been modified to incorporate the EU ETS, a disaggregated electricity sector and facilitate the application of a carbon tax.

6.1 Model description

The UKENVI model is a single-region, multi-sectoral, energy-economy-environment computable general equilibrium model of the UK. It is based upon previous AMOS models used in the Fraser of Allander Institute and, in particular, the framework originally developed in Harrigan *et al* (1991). This model was parameterised on data of the Scottish economy in 1989. The model can be considered a *framework* because it is adaptable and flexible in that it allows for a range of model closures, functional forms and key parameter values. Since then there have been several further extensions of this modelling framework and pertinent to this discussion was Ferguson *et al* (2004) which introduced pollution. A recent application considers the macroeconomic and sectoral effects of changes to energy efficiency and, in particular, the potential for rebound and backfire effects (Allan *et al*, 2007b). Therefore the various behavioural assumptions that can be made, and the fact that any sensitivity analysis can be conducted easily, make the AMOS framework appropriate for the task of modelling the disaggregated electricity sector and implementing a carbon tax. This modelling framework can be applied to any small open economy for which data are available. In this instance we are concerned with the UK.

The model structure has three transactor groups: firms, households and government. Final demand has four components of household consumption, investment, government expenditure and exports. The model consists of well-behaved multi-level production functions while firms are cost-minimisers when producing in competitive markets. In every period all markets are in equilibrium with price equal to marginal cost. Household consumption is a linear function of the population, average income and consumer prices. Government expenditure is assumed to be exogenous and is determined by the initial base-year calibration.

The production functions used are Constant Elasticity of Substitution (CES) which allows for input substitution when relative prices change, although Leontief or Cobb-Douglas production functions are available. Introducing energy into the model is not straightforward. In particular, it is not clear where energy should enter in the production structure within the typical KLEM (capital-labour-energy-materials) nested production function.[109] Energy could possibly substitute with or complement capital and therefore it could enter as part of a value-added composite. Alternatively it may enter the production structure as an intermediate input. Whatever assumption is made will affect substitution possibilities and simulation outcomes. In this instance energy enters as an intermediate input since it is a produced good.

The production structures are the same for twenty-four sectors with the exception of treatment of the electricity supply sector. All elasticities of substitution are required to be set for the CES functions where substitution is possible based upon previous estimates (used in AMOS simulations) and these are listed in Appendix H.[110] For the production structure of each sector in the model we use nested production functions

[109] See Lecca *et al* (2011b) for an investigation of where energy should enter in the production function of CGE models.

[110] A list of all model equations are not given in the PhD due to exhaustive length but can be provided on request.

and they are shown below in Figure 5.5 for all 24 sectors except the electricity supply sector and Figure 5.6 for the electricity supply sector.

For the 24 economic sectors the gross output for each sector is produced by combining the composite intermediate inputs with the composite value added. It is possible to substitute between these two composites. Value added is produced by labour and capital, also with the potential to substitute between them. Intermediate goods can either be produced domestically or imported. Intermediate goods are a composite made up of two sub-composites of energy or non-energy goods. The energy composite can further be split into electricity supply and non-electricity. On the next level non-electricity is a combination of coal and non-coal where non-coal is a composite made up of oil and gas.

When the twenty-four sectors use electricity as an input, all sectors purchase only a single electricity input from the electricity supply sector. However, the electricity supply sector has a different production structure from the other twenty-four. In particular the energy intermediate composite here is much more complicated. The energy composite is split between electricity and non-electricity. The non-electricity functions the same as for all other sectors, however, the electricity sector is completely different. The electricity composite is split between generation and supply. Generation contains a composite of the nine available electricity generating technologies as possible inputs. These generation technologies are split first between intermittent and non-intermittent generation types. Intermittent generators are marine and wind, the latter of which is split between onshore and offshore. Non-intermittent electricity generation technologies distinguish between fossil-fuel generators and low-carbon technologies. The fossil fuel generation combines both coal and gas generation. The low-carbon generation is a composite of nuclear and of renewables which on the next level distinguish between hydro, biomass and landfill gas.

Figure 5.5: Production Structure of all sectors apart from electricity supply sector

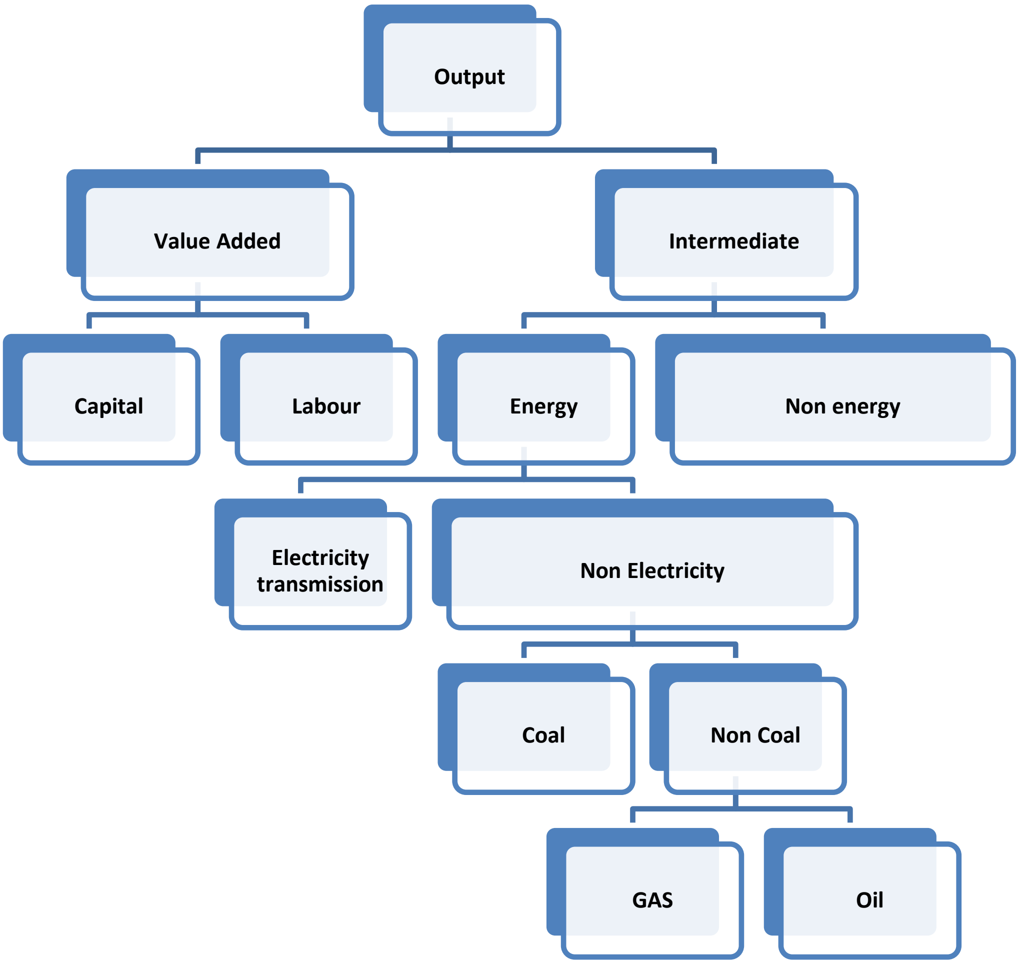
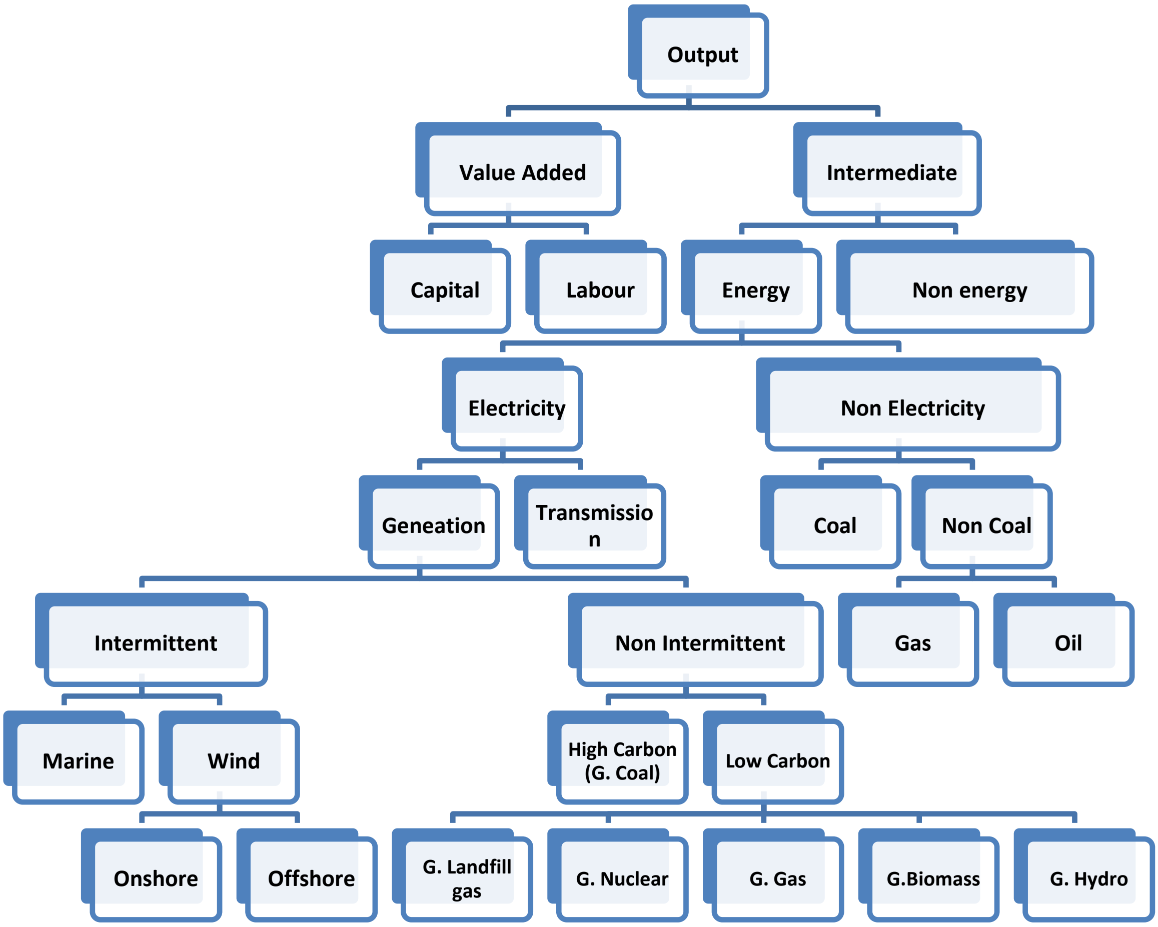


Figure 5.6: Production Structure of electricity supply sector



There are two external sectors with which the UK trades: Rest of European Union (REU) and Rest of World (ROW). Therefore we apply the assumption that the UK is a small open economy which seems appropriate in both the context of trade and climate change. An Armington (1969) link determines the extent of imports and exports to and from the UK and under this assumption domestic and imported goods are imperfect substitutes and so respond to relative prices. The model uses a default Armington elasticity of 2.0 unless otherwise stated.

Investment in the model is determined through profit maximising behaviour and is consistent with the assumption of quadratic adjustment costs. The base year assumes that capital stocks in each sector are initially in long-run equilibrium. These through net investment in each period adjust capital stocks where the model is in a period-by-period mode used in these simulations. Capital stocks initially start in equilibrium where desired and actual capital stocks equate and so investment is equal to depreciation. Capital stocks then update through investment, via a partial adjustment mechanism with an econometrically determined speed of adjustment parameter. Investment is equal to depreciation plus the gap between the actual and desired capital stock. Here the desired capital stock is a function of commodity output, nominal wage and the user cost of capital. The actual capital stock is the previous period's stock net of depreciation and investment.

Therefore the treatment of capital adjustment is consistent with the idea of sectoral investment being determined by the user cost of capital and the rental rate of capital. The user cost of capital is the total cost to a firm of employing a unit of capital and the rental rate is the competitive market price for the capital in a specific sector. The interest, depreciation and capital tax rates are all assumed to be exogenous and so the capital price index is the only endogenous factor of user cost. Where the rental rate is greater than the user cost then desired capital is greater than actual capital stocks and so accumulation of capital is incentivised. This increased accumulation then continually lowers the rental rates until they again equal the user cost.

In the AMOS framework the labour market can be modelled in a variety of ways. This allows for investigation of the sensitivity of simulation results to variation in the functioning of the labour market. A classic CGE model has a full-employment equilibrium. However, incorporating other assumptions can allow for more realistic macroeconomic behaviour such as unemployment or wage and price rigidities. At one extreme it is possible to have an exogenous labour supply (i.e. no migration and a completely inelastic labour supply). Here wages are endogenous but employment and population are fixed with the labour supply inflexible. Another regime is where wages are determined by bargaining and the real wage is inversely related to the prevailing unemployment rate. This assumption is often used in regional simulations. Other possibilities are also available. 'Continuous market clearing' is possible where in every period the real wage adjusts itself in order for supply and demand to be equalised. 'Keynesian/national bargaining', here the nominal wage is set exogenously and labour supply is infinitely elastic until it reaches full employment. 'Real wage resistance' is another possibility where the real wage is fixed with nominal wages varying with the consumer price index.

It is also possible in the model to allow for flow migration to and from the UK where net migration is influenced positively by the real wage and negatively by the unemployment rate. In the long-run equilibrium migration will return to zero.

Another model feature is that it can be solved with either myopic or forward-looking agent behaviour. In the myopic scenario agents have adaptive expectations and so respond to changes in previous periods of the model while in the forward-looking scenario all agents have perfect foresight of future changes.

The initial database used to calibrate the model is a SAM for the UK in 2004. This is based upon the UK Analytical IO Table (Wiedmann *et al*, 2008) together with data from the Blue Book (ONS, 2010b). [111] The Blue Book data is used to create the income-expenditure accounts for households, government, corporations, capital and external sectors and therefore complete the necessary SAM to use for the baseline database.[112]

In the model I have disaggregated the SAM into twenty-five intermediate sectors which are listed in Table 5.4. This disaggregation is intended to identify emissions-intensive sectors which are central to this analysis. Ten of the twenty-five industries are covered by the EU ETS and the remaining sixteen are not. The nine sectors considered as EU ETS traded are aggregated from the IO analysis in Chapter 3. Of

[111] It was necessary to update the 'other value added' entry in the column for the "Coke, refined petroleum and nuclear fuel" sector which had a negative OVA column in the IO accounts. The model could not solve with a negative OVA entry. Therefore this value was updated using more recent data on 2004 from the UK "Use" table published by the ONS.
[112] Developed through Dr Karen Turner's ESRC Climate Change Leadership Fellow project (ESRC ref: RES-066-27-0029) at the Fraser of Allander Institute, Department of Economics, University of Strathclyde, 2009

the 25 sectors in the model, thirteen are energy sectors. Four energy commodities are coal, gas, oil and electricity supply and there are nine electricity generation sectors which sell their output only to the electricity supply sector. This level of aggregation allows me to maintain the richness of the data for many important sectors that previous analysis has suggested are important for climate change related policy questions. In particular this allows substitution between different sources of electricity generation. The disaggregation of the electricity sector is discussed at length in Chapter 4.

Table 5.4: UKENVI economic sectors

25 sectors	Sector Title	UKIO 123 sectors	UK SIC (92) codes	EU ETS
1	Coal Mining and quarrying	4	10	Y
2	Gas Mining and quarrying	5, 86	11, 12, 40.2, 40.3	Y
3	Coke ovens, refined petroleum and nuclear fuel	35	23	Y
4	Other traded e.g. Food and drink	6-19, 21-31, 34, 36-38, 77-80	13 to 15, 17 to 20, 22, 24.11 to 24.14, 34, 35	Y
5	Pulp and Paper	32-33	21	Y
6	Glass and Ceramics	49-50	26.1 to 26.4	Y
7	Clay, cement, lime and plaster	51-52	26.5 to 26.8	Y
8	Iron and Steel; non-ferrous metals	53-56	27.1 to 27.5	Y
9	Generation – Coal	85	40.1	Y
10	Generation -Gas + Oil	85	40.1	Y
11	Electricity distribution and supply	85	40.1	N
12	Generation - Nuclear	85	40.1	N
13	Generation - Hydro	85	40.1	N
14	Generation - Biomass	85	40.1	N
15	Generation - Wind	85	40.1	N
16	Generation - Wind Offshore	85	40.1	N
17	Generation - Other	85	40.1	N
18	Generation - Marine/solar	85	40.1	N
19	Agriculture; Forestry and fishing	1-3	01,02, 05	N
20	Water	87	41	N
21	Construction	88	45	N
22	Other Manufacturing and wholesale retail trade	20, 39-48, 57-76, 81-84, 89-92	16, 24.15 to 24.7, 25, 28 to 33, 36, 37, 50 to 55	N
23	Air Transport	96	62	N
24	Other Transport	93-95, 97-99	60, 61, 63, 64	N
25	Services	100-123	65 to 97	N

6.2 Energy-environment database

In addition to the economic database requirements discussed above it is also necessary for energy-economy-environment CGE modelling to create base year environmental accounts and coefficients. Only CO_2 emissions are considered in the UKENVI model employed here. I do not account for other GHG emissions listed in the Kyoto Protocol such as methane and nitrous oxide. Limiting the analysis to only carbon dioxide provides simplicity given the established linear relationship between fuel use and CO_2 emissions. There are scientific emissions factors between combustion of fossil fuels and the levels of carbon dioxide that this combustion creates. With many other GHG emissions it is not so simple to model input-emissions relationships because emissions depend not only on fuel type but also technology used and specific combustion conditions. This focus solely on carbon dioxide provides consistency with the EU ETS given that CO_2 is the only GHG currently covered by the trading scheme. However, this does pose a problem in assessing UK policy proposals in that the UK carbon budgets, and corresponding emissions reduction targets, are set for all Kyoto gases. Future analysis may well extend the pollutants considered in the model in order to more accurately describe the UK economy but for now I simplify the analysis by concentrating solely on the largest contributor to climate change, carbon dioxide emissions.

In the model I use the method of Beauséjour *et al* (1995) which links emissions to both inputs and outputs. This is because when faced with a carbon tax industry can reduce its emissions either by changing its inputs or, where this is not possible, lowering its output.[113] In the input-output analysis of previous chapters I had linked emissions to output but this simplistic approach does not allow for input substitution. We therefore wish to be able to relate emissions to inputs. In previous analysis during this thesis I have used the Environmental Accounts (EA) from ONS (2010a) which supply data on CO_2 emissions for each economic sector. However, the EA emissions cannot be directly attributed to a specific fuel input; they only give total

[113] Another option not captured by this model is to improve or change technologies used in the combustion process. For instance the commercial implementation of Carbon Capture and Storage would allow significant emissions reductions.

carbon dioxide emissions from each sector. Therefore further work was required to be undertaken to appropriately model the environmental side of the economy by linking emissions to fuel inputs.

The assumption undertaken calculating emissions generated by an economic activity are that they are a linear function of the volume of fuel combusted *and* of the level of output from other polluting processes. Sectoral emissions from the combustion of fossil fuels are linked to fuel inputs from the three economic sectors of 'Coal mining', 'Gas extraction and distribution', and 'Refined petroleum and oils'. These would account for all carbon dioxide emissions from fuel combustion. CO_2 emissions that are not related to combustion are required within the model where economic activities are inherently polluting in their nature. These non-combustion emissions are directly related to output through emissions-output coefficients which state the amount of pollution per unit of output for each of the sectors. Hopefully these non-combustion emissions should be captured by our sectoral disaggregation which concentrates on heavily polluting sectors identified in the EU ETS traded sector.

Therefore, emissions of CO_2, e, for each economic sector, i, should be calculated as:

$$(5.2) \qquad P_i = \sum_{j,t} (e_{ijt} . F_{ijt}) + n_i \;. X_i, \forall\, i = 1, \dots . I, \forall\, j = 1, \dots . J, \forall\, t = 1, \dots . T$$

Where P is total emissions in production in sector i and e is an emissions factor, identifying the amount of carbon dioxide that is generated when sector i uses one unit of fuel j using technology t. F_{ijt} is the physical quantity of fuel j used by sector i with technology t, and n_i is an output-emissions coefficient quantifying the non-fuel-combustion-related generation of carbon dioxide per unit of output in sector i, X_i.

When dealing with final demand in the above equation I replace the output of a sector i with final demand sector z. Total output of sector is replaced by total final household consumption C_z which is t:

$$P_z = \sum_{j,t} (e_{zjt} . F_{zjt}) + n_z . C_z, \forall z = 1, \ldots . Z, \forall j = 1, \ldots . J, \forall t = 1, \ldots . T \quad (5.3)$$

The value of output of each economic sector, X_i, is given in the UKIO table and so is expenditure for each final demand sector, C_z. Therefore it is necessary to have data on the amount of fuel combusted by each industrial sector (F_{ijt} and F_{zjt}) and of the fuel combustion and non-combustion emissions factors (e_{ijt}, e_{zjt}, n_i and n_z). It is then necessary to link emissions to inputs and/or economic outputs for production sectors and final demand. In the model the only part of final demand that I link to emissions is household consumption given data limitations.

The following sections describe in further detail the method employed to calculate the necessary data on fuel use and carbon dioxide emissions for each sector and the linking of carbon dioxide emissions to input use and production of output.

6.2.1 Fuel use

Data was used on ‘fuel use by industry’ (ONS, 2011) for 129 industries plus household use in 2004 of coal, natural gas, petrol, fuel oil, gas oil, aviation fuel and others (including LPG) in tonnes of oil equivalent. These were summed to three fuel types: coal, natural gas and oil/petroleum products. The figures for these three fuels were then aggregated from the 129 industries to each of the corresponding twenty-five economic sectors in the UKENVI model. This gives the use of coal, gas and oil for each economic sector in the model. However, these figures only give total fuel used by an economic sector in 2004 and do not distinguish where the fuel originated from i.e. where it was produced domestically or if it was imported. Therefore other data on imports of fuels to the UK were required. Each fuel was disaggregated between domestic and imported production based upon the share of imports to total supply of each fuel given in Energy Balance data in chapter 1 of DUKES from DECC (2010b). For example, around 60% of coal used in the UK in 2004 was imported. I apply this share across all sectors for the ONS data on ‘Carbon fuel use by fuel type' and so 60% of coal use in each economic sector is imported. More sector specific data on fuel imports would be needed in future to more accurately represent the energy and environmental database.

Electricity consumption for each of the twenty-five economic sectors in the model was calculated using data from DECC energy sector statistics for electricity commodity balances in 2004 (DECC, 2010b). These statistics also provided data on total electricity imports. There was 9,784 GWh of electricity imported to the UK in 2004 which accounts for around 2.5% of total electricity demand in that year. In practice there is a limit on the amount of electricity that can be imported to the UK due to capacity constraints and network limitations. Again at the sectoral level the share of domestic and imported electricity is split based on this share e.g. 2% of every sector's electricity use is imported.

Table 5.5: Fuel use and emissions per sector

2004 total energy use and emissions Sector	Coal (toe)	Gas (toe)	Oil (toe)	Electricity (GWh)	CO2 emissions (thousand tonnes)
Coal Mining and quarrying	53,357	0	74,545	1,118	230
Gas Mining and quarrying	0	7,331,021	556,120	558	24,238
Coke ovens, refined petroleum and nuclear fuel	4,187,812	1,487,523	5,621,692	4,681	20,769
Other traded e.g. Food and drink	201,795	7,380,307	2,481,505	40,892	23,316
Pulp and Paper	142,695	1,768,469	213,553	13,171	4,920
Glass and Ceramics	0	952,325	71,303	4,497	2,992
Clay, cement, lime and plaster	29,372	400,795	361,171	3,037	12,715
Iron and Steel; non-ferrous metals	1,388,786	735,727	5,854,281	12,880	24,528
Generation - Coal	30,526,578	0	15,729	0	115,390
Generation -Gas + Oil	0	26,022,249	174,943	0	57,086
Electricity distribution and supply	0	0	15,729	22,313	7,957
Generation - Nuclear	0	0	15,726	0	45
Generation - Hydro	0	0	0	0	0
Generation - Biomass	0	0	0	0	0
Generation - Wind	0	0	0	0	0
Generation - Wind Offshore	0	0	0	0	0
Generation - Other	0	0	0	0	0
Generation - Marine/solar	0	0	0	0	0
Agriculture; Forestry and fishing	5,416	202,455	1,750,353	4,044	5,882
Water	0	803,857	735,419	623	3,209
Construction	0	242,707	3,235,956	1,804	9,889
Other Manufacturing and wholesale retail trade	380,694	8,086,945	6,056,016	35,185	38,332
Air Transport	0	17,982	13,713,781	0	39,179
Other Transport	0	290,244	18,374,915	4,058	55,536
Services	135,759	6,910,832	3,483,872	95,178	26,198
Households	273,197	34,084,478	28,232,034	124,200	156,990
TOTAL	**37,325,461**	**96,717,916**	**91,038,642**	**368,240**	**629,401**

Source: Coal, gas and oil are ONS (2011), Electricity is DECC (2010b), Emissions are ONS (2010b),

6.2.2 Calculating emissions

The intention is to calculate CO_2 emissions coefficients for each economic sector and final demand sector that link emissions to inputs and outputs. This required an estimate of CO_2 emissions for each sector. There are a number of possible methods for calculating carbon dioxide emissions for 2004. The first is a bottom up approach in which the use of the three fossil fuels of coal, gas and oil, described above, is converted directly from tonnes of oil equivalent into CO_2 emissions using emission conversion factors for company reporting supplied by the Department of environment, farming and rural affairs (DEFRA, 2011). This assumes that emissions are a linear function of the volume of fuel combustion and is most in keeping with the equations 5.2 and 5.3 in Section 6.2 above. However, this method appeared to overestimate emissions from combustion as the total emissions from my calculations were greater those from the Environmental Accounts (EA) given by (ONS, 2010a) which combine both combustion and non-combustion. Total UK carbon dioxide emissions from the EA are 629,401,024 tonnes of CO_2 in 2004 while my calculations from bottom-up fuel data were greater than the EA total by around 38 million tonnes of CO_2. This may be down to a combination of discrepancies between EA data on fuel and corresponding levels of emissions as well as rounding issues on my behalf in converting tonnes of oil equivalent into KWh and then into CO_2.

An alternative method of calculating emissions from fuels was to use data from DECC on total CO_2 emissions from fuel source (DECC, 2011b, Table 4). These data are not split by economic sectors; they simply give the total UK CO_2 emissions from coal, gas and oil. Therefore a limitation of this data was that it was at an aggregate level and also it would only give emissions from fuel combustion and did not non-combustion emissions in any way.

It was then necessary to find a methodology that would include emissions from both combustion and non-combustion processes. I finally settled on a method for calculating carbon dioxide emissions whereby total emissions for each sector are constrained to the EA total and split between combustion and non-combustion on the following basis.

The combustion emissions for each are calculated by splitting the DECC (2011b) totals for each fuel based on that sector's share of total fuel use in 2004. For example, the DECC total emissions related to coal use in 2004 was 145 million tonnes of carbon dioxide. This total amount was then split between sectors based on their use of coal as detailed in the table above. A similar process was implemented based upon DECC figures for emissions from both gas and oil. Almost all of these were smaller than the EA total for twenty-two sectors with the 'Coal mining', 'Coke ovens, refined petroleum and nuclear fuel' and the 'Coal generation' sectors being the exceptions and emissions from these were scaled down slightly to match the EA total for those sectors.

I would also expect significant non-combustion emissions of CO_2 for some sectors. In particular I would expect these types of emissions to occur in EU ETS sectors which are identified in the model from previous analysis. Non-combustion CO_2 emissions in the model are calculated as the excess emissions from the EA less base emissions calculated from DECC emissions from fossil fuels. In the model non-combustion CO_2 emissions account for around 23% of total emissions occurring in the "Cement manufacturing" sector and around 85% of total emissions for "Iron and Steel" manufacturing. This shows that several sectors are inherently polluting in their output and clarifies the reason for the inclusion of these sectors in the EU ETS. Also, around one third of emissions from the 'Oil and gas extraction' sector under this method are linked to sectoral output which can explain emissions that occur during extraction activities.

Emissions were then split between those from domestic and imported fuels on the same method as described above for fuel use.

Once emissions from fuel use for each sector have been determined an input-emissions coefficient for each sector and fuel can be calculated. These coefficients determine the relationship between fuel inputs and emissions and are achieved by dividing emissions related to each fuel by purchases of from that fuel sector in the SAM. Here the underlying assumption made is that all coal, gas and oil inputs from ONS (2011) relate directly to the ‘Coal mining’, ‘Gas extraction and distribution’, and ‘Refined petroleum and oils’ sectors in our economic database. For example ‘Agriculture’ has an input-emissions coefficient for coal which is calculated by its emissions from domestic coal (based on its use of coal fuel) divided by Agriculture’s domestic purchases from ‘Coal mining’ sector in the SAM. The same will also be calculated from imports using the share of emissions from imports linked to the import matrix. The ‘Agriculture’ sector will also have input-emissions coefficients for domestic and imported gas and oil as well as an emissions coefficient linked to output. Therefore emissions coefficients for each fuel will vary across economic sectors as a by-product of the data used and these are listed in Table G1 of Appendix G.

7. SIMULATION APPROACH

Using the model outlined above I wish to simulate the fulfilment of the UK carbon budget of a 34% reduction in UK GHG emissions by 2020 compared to 1990 levels. However, there are two considerations which make undertaking this simulation not quite so simple. Firstly, the model is for 2004, and secondly, the model only considers CO_2 and not all GHGs. There is no specific target for CO_2 reductions. All targets are set in terms of total GHGs. This is an important distinction especially given that between 1990 and 2004 total UK GHG emissions fell by 84,266 thousand tonnes of CO_2 equivalent (around a 10% reduction) while actual CO_2 emissions rose by 5,401thousand tonnes (just under a 1% increase).[114] The entirety of the GHG reduction came from gases other than CO_2. I assume therefore in the model that the reduction in CO_2 emissions by 2020 must be at least as large as the overall GHG reduction of 34% from 1990 levels because it will become more difficult to make

[114] For every year between 1990 and 2003 except 1991 the UK carbon dioxide emissions were lower than the base year level but never by more than 5%. 1995 was the lowest. In 2004 the CO_2 level was higher than the base year.

significant cuts from non-CO2 GHGs in the future since these have already significantly reduced. I therefore simulate a reduction in CO_2 emissions of 35% from 2004 levels by 2020 which corresponds to a reduction in carbon dioxide of 34% from 1990 levels. The numerical simulations are run using GAMS (General Algebraic Modelling System) software.[115]

An *ad valorem* carbon tax in the UK is simulated via an increase in the prices of coal, gas and oil based on the carbon content of each fuel. A carbon tax of £22 per tonne of CO_2 is initially introduced across all sectors.[116] This results in an increase in the price of coal of 56%, the price of oil by 21% and gas by 14%. These price changes will result in general equilibrium effects whereby there is substitution away from these fossil-fuel inputs into production and inter-fuel substitution where possible.

The tax is intended to be revenue-neutral and therefore I undertake three different simulations with regards to how revenues which accrue to the public sector from the tax are redistributed. There is a baseline scenario where none of the revenues are recycled. This is equivalent to a situation where revenues are kept by an outside body. The baseline scenario is compared against a case where revenues are recycled through increased government expenditure and another case where the revenue is used to reduce income taxes. I would expect emissions to drop in all scenarios. Of the three scenarios, I would expect emissions to fall the most in the no recycling scenario but also for output and employment to fall the most as well. Where revenue is used to increase government spending I would expect aggregate demand to rise and therefore output and employment to increase. I would also expect similar results for the reduction in income taxes which should increase household disposable income and therefore stimulate output and employment. This should have positive impacts on competitiveness through the labour market. Both recycling cases should partially or wholly offset the negative distortionary effects of the carbon tax and possibly lead to a double dividend in the UK.

[115] For details of GAMS see their website http://www.gams.com

[116] The correct carbon tax level is achieved through trial and error to achieve the necessary emissions reduction target.

The aggregation of EU ETS traded and non-traded sector allows alternative specification of the sectors to which the carbon tax is applied i.e. the tax base. For instance, it is possible to apply the carbon tax solely to those traded sectors that are covered by the EU ETS. The disaggregation of the electricity sector into various generation technologies allows this simulation to be implemented. However, in the simulations here I concentrate on a carbon tax applied to all sectors of the economy. The EU ETS simulations will be a further extension after the thesis.

There are also several possible specifications for the labour market in the UKENVI model, although they all impose a unified national labour market with perfect sectoral mobility. The baseline scenario employs a regional bargaining function in which the real consumption wages is inversely related to the unemployment rate and population is assumed to be fixed. The bargaining function parameterisation for the UK follows Layard et al (1991):

$$w_t = \alpha - 0.06u + 0.4w_{t-1} \tag{5.4}$$

where w is the natural logarithm of the UK real consumption wage nominal wage rate, u is the natural logarithm of the unemployment rate, t is the time subscript and α is a parameter calibrated so as to replicate equilibrium in the initial period.

The model employs forward-looking expectations where the savings rate is made endogenous as a national economic system is being considered.[117] This assumes that households are the ones responsible for all financial needs in the economy. Household wealth is therefore related to foreign debt, firms' value and Government debt, where bonds borne exclusively by households are used to finance the Government debt (Lecca *et al*, 2011a). Long run results are presented after 16 periods due to the emissions reduction target however, capital stocks do not fully adjust until thirty periods and so will not be fully adjusted for the period of consideration.

[117] See Lecca *et al* (2011a) for a discussion of forward-looking versus myopic computable general equilibrium models and on the difference between endogenous and exogenous savings rates.

To conduct a sensitivity analysis a number of alternative specifications of key assumptions are simulated. Alternative assumptions regarding elasticities of substitution at various points of the production structure allow sensitivity analysis to show how varying these elasticities can affect results. In particular, I would expect the rates of substitution between electricity and non-electricity and also between the various electricity generation technologies to be important as to the extent to how the economy can adapt to the tax. Therefore I carry out alternative scenarios (Elast1 and Elast2) to determine the impact that varying these parameters. The details of the various differing elasticity assumptions are given in Appendix H.

An alternative specification of the labour market is also simulated where I impose a Real Wage Resistance closure. Here a fixed real consumption wage is imposed on the model and so employment must vary to bring the labour market into equilibrium. This assumption implies effectively that the labour supply is infinitely elastic and so could be considered as similar to a scenario that has perfect flow migration. This provides a useful comparison to the baseline scenario.

8. RESULTS

This section gives the results of the various simulations carried out using the UKENVI model for the three different scenarios as to how revenues from the carbon tax are used.

8.1 Macroeconomic results

Table 5.6 shows the overall macroeconomic results of the carbon tax in each of the three alternative revenue scenarios of no recycling (NR), income tax (IT) and government expenditure (GE). All numbers are expressed in terms of percentage changes from the equilibrium base year scenario of 2004. The short-run and long-run results are for 2005 (period one, where capital is fixed) and 2020 (period sixteen, where capital can adjust, although not fully) respectively.[118] 2020 results are reported because that is the year of the emissions reduction target of 35% which I aim to achieve. No migration takes place in the simulations.

Table 5.6: Impact of a £22 carbon per tonne carbon tax on key macroeconomic variables in the UK

UK Carbon tax: 22£ per tonnes of CO2	No recycling		Income tax		Gov_Expend	
Regional Bargaining Fixed labour supply	SR	LR	SR	LR	SR	LR
Emissions	-28.40	-35.18	-28.18	-34.87	-28.58	-35.43
Income Tax	Eps	Eps	-2.39	-2.07	Eps	Eps
GDP	-0.07	-1.22	0.25	-0.68	-0.09	-1.13
Consumer Price Index	-0.47	-0.25	-0.46	-0.38	-0.18	-0.07
Unemployment Rate	1.52	10.91	-6.45	2.20	1.92	10.11
Total Employment	-0.10	-0.70	0.41	-0.14	-0.12	-0.65
Nominal Gross Wage	-0.57	-1.40	-1.21	-1.65	-0.30	-1.14
Real Gross Wage	-0.10	-1.15	-0.75	-1.27	-0.13	-1.07
Real Wage after Tax	-0.10	-1.15	0.45	-0.23	-0.13	-1.07
Replacement cost of capital	-1.57	-0.16	-1.07	-0.29	-0.76	0.03
Labour supply	Eps	Eps	Eps	Eps	Eps	Eps
Households Consumption	-0.43	-0.61	-0.04	-0.11	-1.29	-1.38
Gov Consumption	-	-	-	-	1.94	2.23
Net investment	-2.26	-2.30	-1.87	-1.74	-2.66	-2.11
Capital Stock	Eps	-2.11	Eps	-1.60	Eps	-1.95
Export	1.06	0.32	1.19	0.55	0.81	-0.02

In all cases total emissions are reduced in the economy to meet the reduction target of 35% by 2020 except under IT recycling where it is missed but only by 0.13%. Across all three recycling scenarios GDP, employment levels, real wages and household consumption all fall and therefore there is no double dividend achieved

[118] The economy is not yet fully adjusted after sixteen periods, this happens after thirty periods. Therefore the results reported as long run are not necessarily long run in the sense that capital stocks are still adjusting to their equilibrium.

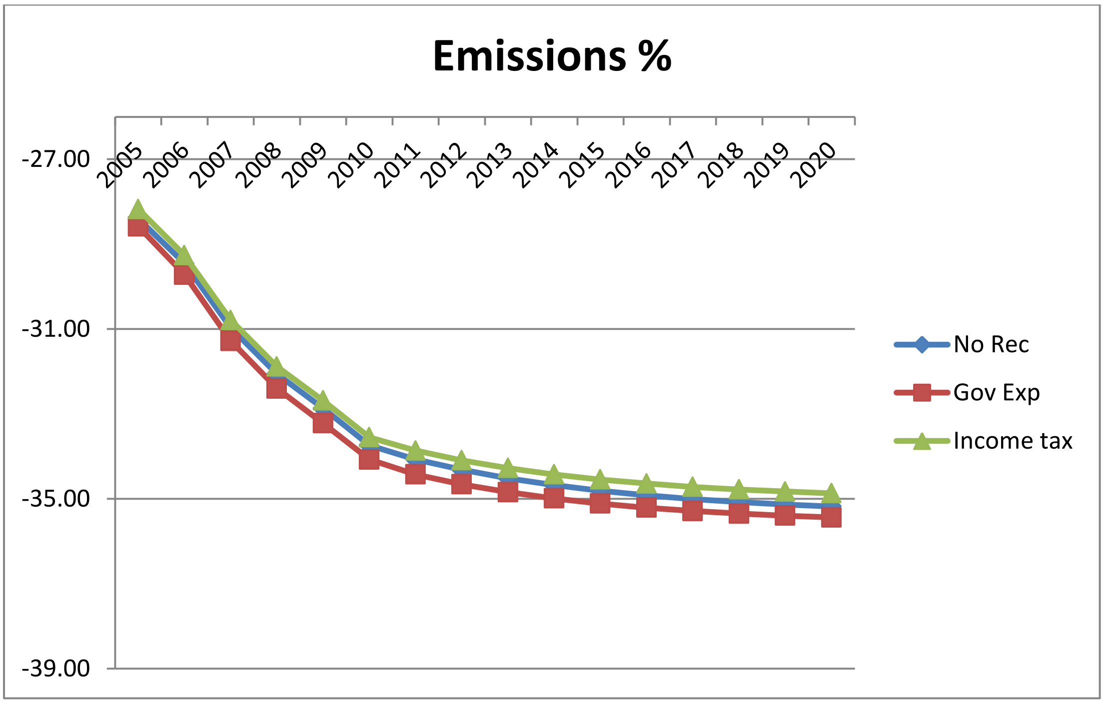
for this carbon tax level. It is interesting to compare the different methods of how revenue recycling is treated in the model.

Where revenues are not recycled at all total emissions in the UK fall by 35.18% in the long-run because the prices of fossil-fuels increase and the negative costs of the carbon tax are not offset at all by recycling of revenues. Most of this takes place in the first period where overall emissions are reduced by 28.4%. The carbon tax has a contractionary effect on the UK economy. The GDP measure decreases the most when revenues are not recycled at all with a 0.07% fall in the short-run and a 1.22% fall in the long-run. This economic contraction is caused by increase in prices of fossil fuels to which the carbon tax applies and energy goods which use these fuels as an input to production. A reduction in household consumption occurs through reduced real wages of 1.15%. Household consumption is reduced by 0.61% over the first sixteen years to 2020. Both the consumer price index (CPI) and nominal wage have fallen although the latter to a greater extent. The CPI actually falls even though there is a price increase in electricity due to the carbon tax. This CPI increase occurs because the price of other sectors, such as ‘Services’, actually decrease slightly and these consist of a substantial part of household consumption. Also, there is a lower capital stock in 2020 of 2.11% compared to 2004. The fall in GDP appears to be lead by the reduced level of net investment of 2.3% in 2020. The fall in GDP is slightly offset by a small crowding in of exports in the results, initially due to the price decrease in several exporting sectors, but this effect lessens over time.

For the case where the revenues from the £22 carbon tax are recycled in order to reduce income tax (IT) then income tax is reduced by just over 2% in the long-run. Where revenues are recycled through IT, emissions fall the least of all recycling methods (34.87%) because the tax reduction stimulates household consumption and investment, relative to the no recycling case, which increases output relative to that case, partially offsetting the reduction in output from the carbon tax, but also therefore increases the emissions associated with raised output. The increase in exports, compared to No Recycling case, will also increase production and the emissions associated with it. The emissions reduction target of 35% is not actually met until 2029 under IT recycling. A carbon tax rate greater than £22 would be required to make sure the target was achieved in a timely manner in this model. Under IT recycling GDP actually rises in the short-run but has fallen by 0.68% in 2020. The effect on employment is also positive for the first eight periods but becomes negative as it approaches long-run equilibrium. This is because the real wage after tax increases under IT for the first eight periods, due to the recycled revenues, but falls as the amount of income tax revenue reduces over time due to substitution away from fuel-intensive goods. The real wage after tax in 2020 has fallen by 0.23% compared to the base year. This increased real wage means that household consumption is positive, compared to the base year, between 2006 and 2015 and negative thereafter. Net investment falls but not by as much as the No Recycling case. The net effect of all these forces in the short-run is expansionary pushing up real wage, household consumption and employment. However, as capital begins to adjust to a lower level the overall effect is negative on the economy.

Finally, where revenues of the carbon tax are used to finance an increase in government expenditure (GE) then government consumption increases by 1.94% in the short-run and 2.2% in the long-run. Total emissions fall the most under GE recycling of all three recycling scenarios. This result seems odd as the increase in government expenditure alone stimulates output which is associated then with higher emissions but the opposite result is found. However, in the GE case emissions fall the most because the increase in government expenditure crowds out household consumption and exports, unlike the other recycling cases, and so emissions fall even more than No Recycling or Income Tax cases. The extent of this may be dependent upon the labour market assumptions and in this case the elasticity on the bargaining real wage curve. In this case GDP has fallen by 1.13% in 2020 which is not quite as negative an impact as the No Recycling case but still a larger fall in GDP than the IT case. The expenditure stimulus is able to only offset the adverse effects of the tax to a small extent. As the increased government consumption replaces household consumption, which falls by 1.38% in 2020, the lower multiplier effect of this reduces the impact of the recycling. Net investment falls the most of the three recycling scenarios in the short run which explains the fact that GDP contracts the most in period 1 of GE when comparing all the cases. However, the government spending stimulus appears to somewhat offset the net investment reduction in 2020 when compared to the No Recycling case. Also, exports are lower in the long run by 0.35% under the GE case compared with no recycling.

Figure 5.7: Change in total UK CO_2 emissions for three revenue recycling methods of £22 carbon tax



Figures 5.8 and 5.9 give the overall effects of the carbon tax on GDP and employment for the three recycling cases between 2004 and 2020. As can be seen the no recycling case has a negative impact on GDP throughout this period and has the lowest GDP of the three in 2020. The GE case has the sharpest decline in GDP for the first five periods but begins to flatten out over the rest of the period until it is at a higher level in 2020 than the recycling case. The IT recycling case has a positive effect on GDP for the first two periods and by 2020 has fallen to about half of the level of the fall in the no recycling case. The employment results are similar although the positive employment effects last for seven periods.

Figure 5.8: Change in GDP for all three recycling methods of a £22 carbon tax

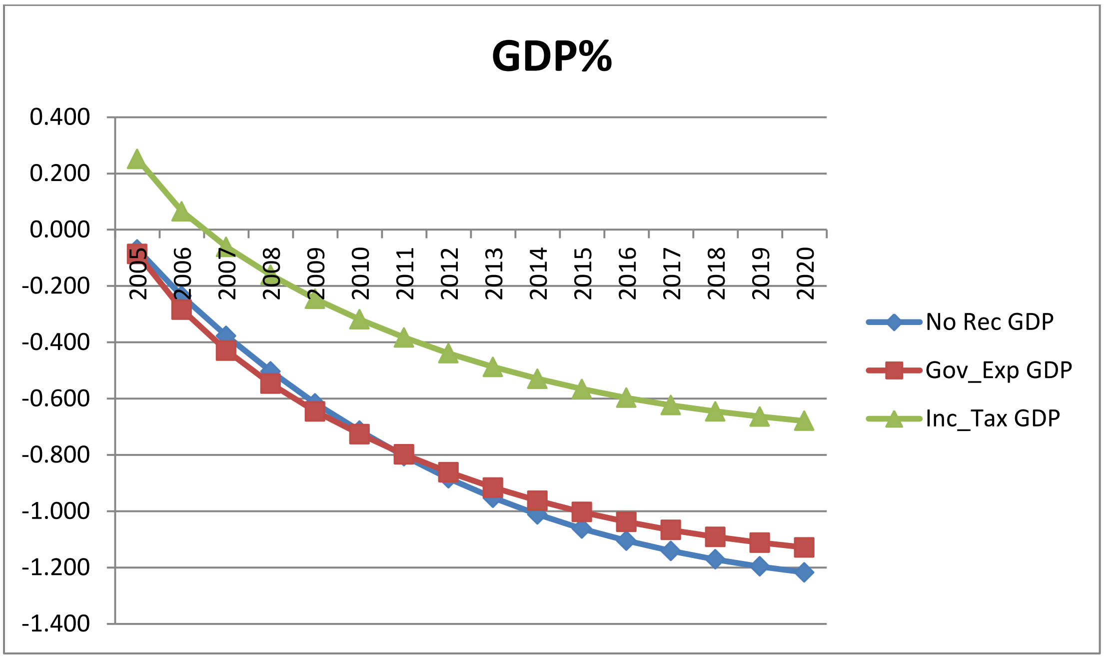
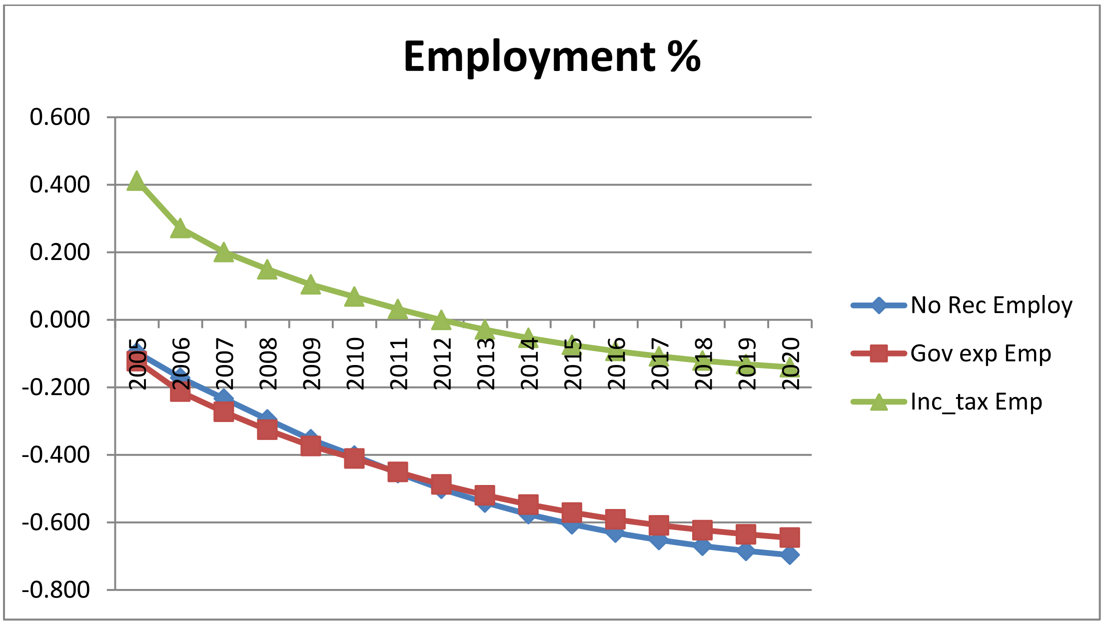


Figure 5.9: Change in employment for all three recycling methods of a £22 carbon tax



8.2 Sectoral results

Figure 5.10 shows the effects of the carbon tax on the commodity price of each of the twenty-five economic sectors under the No Recycling scenario. The tax substantially increases the commodity prices of the three fossil-fuel sectors of coal, gas, and oil, which in turn increases the prices of some other sectors which rely heavily on these fossil-fuels as inputs to production. Many of the EU ETS traded sectors which use these fuels are affected by the higher fuel prices, for instance the “Clay, cement, lime and plaster” and the “Iron and steel” sectors see small commodity price increases of 1.23% and 0.07% respectively. In particular, both coal and gas electricity generation see price increases of almost 15% and 10% respectively by 2020 although in the first period, where capital is fixed, their prices fall very slightly. In turn the commodity price of the “electricity supply” sector also increases by around 6% in 2020. “Air Transport” also sees a price increase due to the increased price of fuel inputs.

The price increase effects described here are slightly lessened under IT and slightly increased under GE in most sectors. Prices effects, and therefore changes in output, are greater in the long run because capital is fixed in short run and significant adjustments to the long run capital stock in fossil fuel energy sectors occur over many periods. On the other hand, the prices of low-carbon electricity generating technologies all fall although in all instances by less than 1% by 2020. In practice technology improvement would reduce these prices substantially more over time but this is no incorporated in the model.

Many other sectors see small reductions in their commodity prices too. The prices of these sectors, such as “Services”, have fallen because they are labour-intensive sectors and will have a reduced price of labour as an input to production. The capital stocks of all sectors, except the seven low-carbon technologies, fall to varying extents by 2020, the largest reductions being in the fossil-fuel and carbon-intensive electricity generation sectors.

Figure 5.10: Percentage changes in commodity prices in short and long run for a carbon tax of £22 per tonne of CO_2 with no revenue recycling

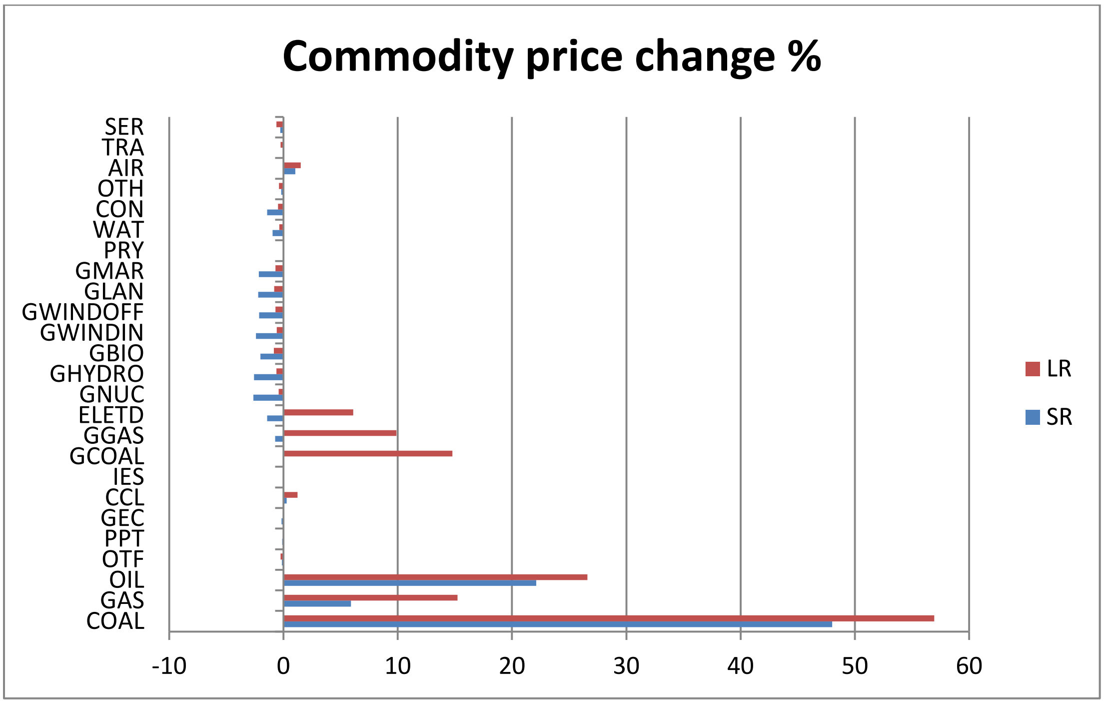


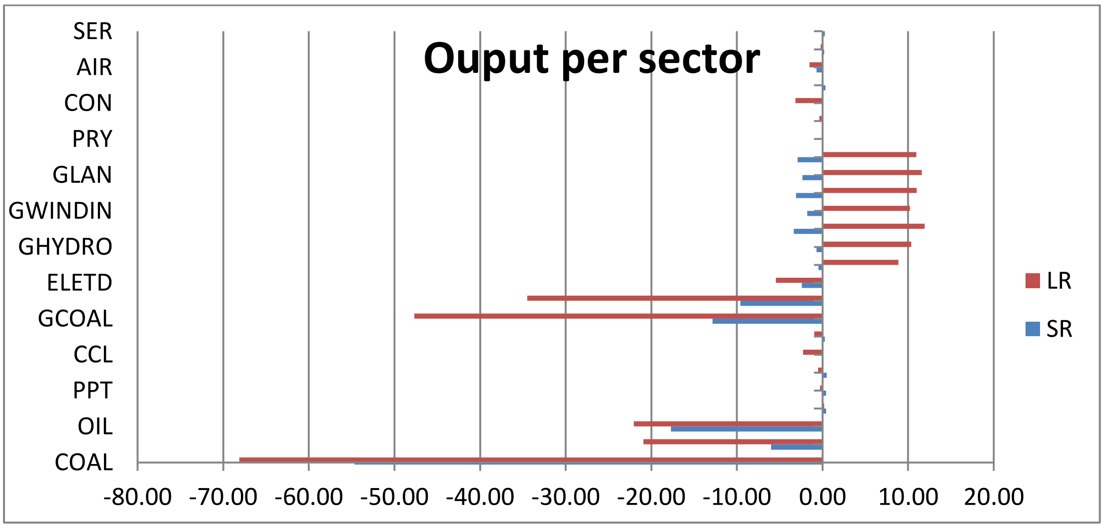
Table 5.7 and Figure 5.11 show the effect of the carbon tax on the output of each sector in the short and long run for each method of recycling. Under NR the output of almost of every sector is reduced to some extent in 2020 except for low-carbon electricity generating technologies. In particular, the outputs of energy sectors are significantly reduced. Output of the "Coal", "Gas" and "Oil" energy sectors fall by 68%, 21% and 22% respectively while the electricity generation from gas and coal are reduced by 35% and 48% respectively. This occurs in the first energy sectors because the carbon price directly increases their price and so output is reduced, and for the generation sectors because the cost of inputs into these sectors has risen and so demand for them falls. There is therefore substitution away from these fossil-fuel sectors towards the low-carbon generation technologies which actually increase their output by around 8-11% in the long-run although they initially fall in the short-run because of the contraction in "Electricity supply" output while capital is fixed. The low-carbon technologies are the only sectors which see an increase in their capital stock by 2020. Output of the "Construction" sector also sees a decline of around

4.5% when taxes are not recycled and 3% under IT and 3.5% under GE. However, under IT recycling there is a small positive effect on the "Other traded" sector, which includes goods such as food and drink, and the "Other manufacturing" sector which are important in household consumption.

Table 5.7: Impact of a £22 per tonne carbon tax on sectoral output in each of three recycling methods

Carbon tax: 22£ per tonnes of CO_2	No recycling		Income tax		Gov_Expend	
Regional Bargaining Fixed labour supply	SR	LR	SR	LR	SR	LR
COAL	-54.86	-68.25	-54.68	-68.12	-54.99	-68.38
GAS	-6.08	-21.19	-6.02	-20.94	-6.19	-21.56
OIL	-17.89	-22.28	-17.73	-22.05	-18.02	-22.47
OTF	0.06	-0.30	0.42	0.21	-0.31	-0.74
PPT	0.03	-0.84	0.42	-0.29	-0.27	-1.21
GEC	-0.02	-1.17	0.49	-0.51	-0.19	-1.45
CCL	-0.63	-3.24	0.03	-2.28	-0.23	-2.95
IES	-0.28	-1.67	0.27	-0.97	-0.24	-1.76
GCOAL	-13.04	-47.86	-12.87	-47.68	-13.09	-48.03
GGAS	-9.85	-34.69	-9.61	-34.49	-9.77	-34.95
ELETD	-2.63	-5.97	-2.43	-5.46	-3.00	-6.46
GNUC	-0.54	8.47	-0.47	8.87	-0.59	7.69
GHYDRO	-0.82	9.68	-0.71	10.34	-1.00	8.83
GBIO	-3.63	10.95	-3.36	11.92	-4.73	10.16
GWINDIN	-1.70	9.50	-1.80	10.21	-2.36	8.80
GWINDOFF	-3.09	10.14	-3.10	10.98	-4.16	9.44
GLAN	-2.67	10.69	-2.34	11.59	-3.27	9.95
GMAR	-2.90	10.10	-2.91	10.94	-3.91	9.41
PRY	-0.17	-0.68	0.05	-0.12	-0.54	-1.36
WAT	-0.13	-0.87	0.02	-0.35	-0.40	-1.46
CON	-1.05	-4.58	-0.12	-3.16	-0.13	-3.67
OTH	-0.04	-0.54	0.35	0.04	-0.51	-1.04
AIR	-0.97	-1.97	-0.71	-1.54	-1.24	-2.34
TRA	-0.12	-0.73	0.21	-0.21	-0.45	-1.05
SER	0.03	-0.55	0.27	-0.13	0.21	-0.14

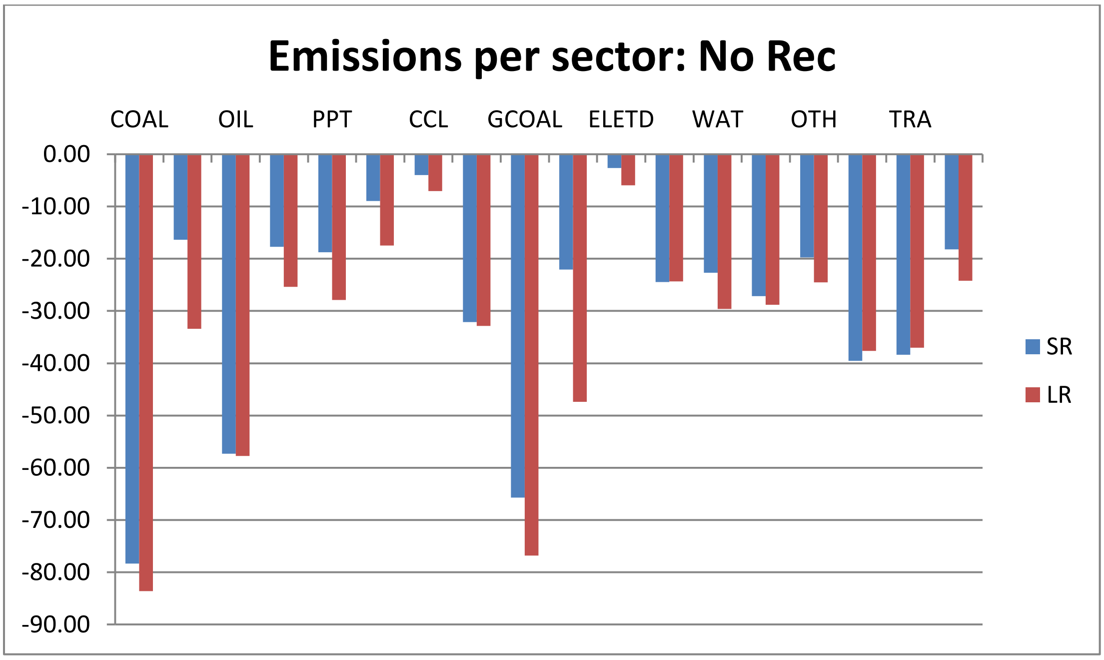
Figure 5.11: Percentage change in sectoral output of a £22 per tonne carbon tax under 'No recycling' scenario



All sectors reduce the emissions associated with their use of fossil-fuels compared to the base year because the output of each sector has declined. The only exception is for the six low-carbon electricity generation technologies where output has increased but emissions have not. Since emissions in the model are not linked to any of the low-carbon electricity generation sectors then by assumption the emissions from these sectors are always zero. Therefore any substitution away from other sectors to these low-carbon technologies will, *ceteris paribus*, lower overall emissions in the economy.

Figure 5.12 gives a breakdown of the individual effects of the tax on emissions from each sector under the No Recycling scenario in the short run and by 2020. In all three recycling scenarios there are substantial reductions in CO_2 emissions from the three fossil-fuel energy sectors and also from the two fossil-fuel electricity generating sectors. Emissions from the "Coal", "Gas" and "Oil" energy supply sectors have fallen by 83%, 33% and 58% in 2020 respectively while emissions from coal electricity generation falls by 77% and gas electricity generation by 47% in 2020. These reductions are caused by the carbon price increasing the commodity price of these sectors which in turn decreased their output level described above. The increase in prices of these fossil fuel electricity generation sectors causes substitution from these towards the seven low-carbon electricity generation technologies. Therefore decreased production in 'gas and oil' and 'coal' generation and increased production in low-carbon sectors means that while total electricity production falls by 5 or 6 percent, the emissions associated with electricity production fall dramatically. Also, emissions associated with all forms of transport fall by about 37% and the "Iron and steel" industry sees its emissions diminish by 33% by 2020. These reductions occur because transport in general requires substantial fossil-fuel inputs which are now more expensive.

Figure 5.12: Percentage change in emissions per sector of a £22 per tonne carbon tax under 'No recycling' scenario



8.3 Sensitivity analysis

The assumptions regarding substitution between nodes in the production function can have an effect on the overall impact and path of adjustment of the policy shock, in this case the carbon tax. Therefore I compare the baseline scenario carbon tax results discussed above in Sections 8.1 and 8.2 with the results from simulations with alternative assumptions about factors which are likely to impact on the effect of the carbon tax.

Firstly, I altered the elasticity of substitution between electricity and non-electricity in the production structure from 2 to 0.3 and keep all other variables the same. The results for the simulations of the Elast1 Scenario configuration are shown in Table 5.8.

Table 5.8: Elast1 - Impact of a £22 per tonne carbon tax where elasticity of substitution between elect vs. non-elect is 0.3

Carbon tax: 22£ per tonnes of CO2 - UK	No recycling		Income tax		Gov_Expend	
Elast1	SR	LR	SR	LR	SR	LR
Emissions	-28.24	-35.18	-28.01	-34.88	-28.42	-35.45
Income Tax	Eps	Eps	-2.40	-2.07	Eps	Eps
GRP Income measure	-0.08	-1.22	0.24	-0.68	-0.10	-1.13
Consumer Price Index	-0.44	-0.25	-0.43	-0.38	-0.15	-0.07
Unemployment Rate	1.75	10.91	-6.24	2.20	2.15	10.10
Total Employment	-0.11	-0.70	0.40	-0.14	-0.14	-0.64
Nominal Gross Wage	-0.56	-1.40	-1.20	-1.64	-0.29	-1.14
Real Gross Wage	-0.12	-1.15	-0.77	-1.27	-0.14	-1.07
Real Wage after Tax	-0.12	-1.15	0.44	-0.23	-0.14	-1.07
Replacement cost of capital	-1.56	-0.16	-1.07	-0.29	-0.76	0.03
Labour supply	Eps	Eps	Eps	Eps	Eps	Eps
Households Consumption	-0.45	-0.61	-0.07	-0.11	-1.31	-1.38
Gov Consumption	-	-	-	-	1.95	2.23
Net investment	-2.24	-2.30	-1.86	-1.74	-2.65	-2.11
Capital Stock	Eps	-2.11	Eps	-1.60	Eps	-1.95
Export	1.06	0.32	1.19	0.55	0.81	-0.02

The change of elasticity to 0.3 affects the short-run results in the first period. Under this scenario the initial fall in GDP and employment is slightly greater under the new Elast1 assumption with a 0.08% and 0.11% fall respectively compared to 0.07% and 0.1% in the baseline scenario. However, the long-run results are not particularly affected by the new elasticity assumption as in 2020 all macroeconomic results are the almost identical to the baseline scenario. This is partly due to the price ratio between electricity and non-electricity not changing much. In terms of individual sectors the sectoral output of coal and gas electricity generation only fall by around 11% and 4% in the short-run under the new elasticity assumption compared to about 13% and 10% previously (Table 5.6). This new assumption with regards to substituting between electricity and non-electricity actually makes it more difficult to achieve emissions reductions in the short term because there are less substitution possibilities away from carbon-intensive production processes.

Secondly, the Elast2 simulation is carried out where the elasticity of substitution between renewable sources is doubled from 5 to 10 and the results of this are detailed in Table 5.9. In particular the new elasticity applies to substitution between intermittent and non-intermittent generation, between onshore and offshore wind, between wind and marine, and between low-carbon and high-carbon sources.

Table 5.9: Elast2 - Impact of a £22 per tonne carbon tax where elasticity of substitution between electricity generation technologies is 10

Carbon tax: 22£ per tonnes of CO2 - UK	No recycling		Income tax		Gov_Expend	
Elast2	SR	LR	SR	LR	SR	LR
Emissions	-28.47	-38.25	-28.25	-37.99	-28.62	-38.47
Income Tax	Eps	Eps	-2.38	-1.89	Eps	Eps
GRP Income measure	-0.07	-1.25	0.25	-0.76	-0.08	-1.17
Consumer Price Index	-0.48	-0.28	-0.48	-0.40	-0.18	-0.10
Unemployment Rate	1.49	10.96	-6.42	2.98	1.85	10.20
Total Employment	-0.10	-0.70	0.41	-0.19	-0.12	-0.65
Nominal Gross Wage	-0.58	-1.43	-1.22	-1.66	-0.30	-1.18
Real Gross Wage	-0.10	-1.16	-0.75	-1.26	-0.12	-1.08
Real Wage after Tax	-0.10	-1.16	0.45	-0.32	-0.12	-1.08
Replacement cost of capital	-1.59	-0.19	-1.13	-0.31	-0.79	-0.02
Labour supply	Eps	Eps	Eps	Eps	Eps	Eps
Households Consumption	-0.41	-0.58	-0.05	-0.12	-1.24	-1.31
Gov Consumption	-	-	-	-	1.93	2.11
Net investment	-1.90	-2.39	-1.52	-1.89	-2.28	-2.22
Capital Stock	Eps	-2.20	Eps	-1.73	Eps	-2.05
Export	1.06	0.37	1.21	0.58	0.79	0.04

These new assumptions increase the substitution possibilities between the various electricity generation technologies. In this instance significant emission reductions are much faster to achieve as substitution from high-carbon goods and inputs towards low-carbon ones is greater and by 2020 overall emissions in the economy have fallen by 38% even under IT which is the most difficult scenario to achieve reductions. In fact the 35% emissions reduction target is met by 2010 in all instances. The long-run macroeconomic effects in 2020 under Elast2 assumptions are relatively greater than the baseline scenario with GDP falling by 0.76% and employment falling 0.17% under IT recycling compared to 0.68% and 0.14% in the original baseline scenario. Therefore, under these alternative Elast2 assumptions where it is easier to switch to renewables, GDP is reduced and it is less likely that a double dividend could be achieved for simulations of the UK economy.

When the labour market closure is altered it is possible to consider how a different assumption with regards to the labour market will change the effect of the carbon tax. The macroeconomic results under the Real Wage Resistance (RWR) closure are detailed in Table 5.10. Under this assumption the real wage is fixed and thus the labour supply is completely elastic. Compared to the National bargaining closure in the baseline scenario the depressing effects of the carbon tax are more pronounced and as such total emissions fall by slightly more in this instance. Under IT recycling GDP and employment fall by 1.82% and 1.33% respectively with the Real Wage Resistance scenario, compared to a fall of only 0.68% and 0.14% under the baseline scenario with a Bargaining closure. The fall in GDP and employment is substantially greater under the No recycling and Government expenditure scenarios. This occurs because in the original case the real wage falls when the carbon tax is introduced but when it is not possible for the real wage to adjust then the demand for labour falls which reduces employment and output to a greater extent. Therefore in this scenario the nominal wage and CPI increase by the same amount as a result of real wages being unable to change. The capital stock falls substantial more when the real wage is fixed under all recycling scenarios. Under IT recycling the capital stock falls 5.13% compared to only 1.6% with this recycling method in the baseline case. However, although the emissions reduction in 2020 is greater under Real Wage resistance than the Bargaining scenario (due to lower output), the fall in emissions is not as great as the fall in GDP. Under the No Recycling scenario emissions fall by around 3% more with Real Wage Resistance than in the baseline case but GDP and employment fall by almost 5% more. This is explained by the fact that there are similar reductions in output of emissions-intensive sectors under both labour market scenarios (although slightly larger falls in these sectors under RWR) but much larger falls in output of labour-intensive sectors. For instance, in the “Primary” sector, which includes agriculture and forestry, output falls by 0.7% in the baseline Bargaining scenario but by 5.1% in the scenario where the real wage is fixed.

Table 5.10: Impact of a £22 per tonne carbon tax on macro variables with Real Wage Resistance

Carbon tax: 22£ per tonnes of CO_2 - UK	No recycling		Income tax		Gov_Expend	
Real wage resistance	SR	LR	SR	LR	SR	LR
Emissions	-29.69	-38.02	-28.33	-35.43	-29.72	-38.13
Income Tax	Eps	Eps	-2.40	-2.05	Eps	Eps
GRP Income measure	-0.40	-6.14	0.39	-1.82	-0.36	-6.06
Consumer Price Index	-2.38	0.22	-1.06	-0.42	-1.52	0.44
Unemployment Rate	9.44	91.43	-9.99	20.91	8.65	90.05
Total Employment	-0.60	-5.84	0.64	-1.33	-0.55	-5.75
Nominal Gross Wage	-2.38	0.22	-2.25	-1.44	-1.52	0.44
Real Gross Wage	0.00	Eps	-1.20	-1.03	0.00	Eps
Real Wage after Tax	0.00	Eps	0.00	0.00	Eps	Eps
Replacment cost of capital	-5.22	0.21	-1.84	-0.37	-3.57	0.43
Labour supply	Eps	Eps	Eps	Eps	Eps	Eps
Households Consumption	-3.60	-5.77	-0.82	-1.37	-4.30	-5.93
Gov Consumption	Eps	Eps	Eps	Eps	3.23	1.57
Net investment	-3.87	-8.11	-1.95	-3.23	-4.54	-8.07
Capital Stock	Eps	-6.66	Eps	-2.65	Eps	-6.60
Export	4.02	-0.60	2.22	0.60	2.90	-1.00

9. CONCLUSIONS AND POLICY ISSUES

In this chapter I attempt to model the economy-wide effects of a carbon tax on the UK economy. A carbon tax could be introduced in the UK as an additional means of achieving the carbon budgets or, as is happening in 2013, as a price floor to the EU ETS. Two main differences from previous CGE models of the UK are the separate identification of the EU ETS "traded" and "non-traded" sectors and the disaggregation of the electricity sector into various generating technologies. Both of these appear to be essential additions to any energy-economy-environment analysis of the UK and these will be fully explored in further work beyond this thesis.

It is clear that in the UKENVI model, a carbon tax will achieve its primary objective of reducing carbon dioxide emissions by 35% by 2020 in most cases. When a carbon tax of £22 per tonne of CO_2 is introduced there is an overall reduction of emissions of 35% from 2004 levels. When the carbon tax is introduced we see inter-fuel substitution between the non-electricity energy sectors from coal to gas and oil. There is also considerable substitution between the different types of electricity generation away from coal and gas generation towards the low-carbon technologies, all of which see an increase in output. Perhaps a limitation of the model is that it does not realistically capture the fact that much of the capital for electricity generation will be fixed for years or decades at a time. Therefore an extension of this work may be to undertake simulations where the capital stock is fixed for a number of periods in certain sectors such as coal, gas and nuclear electricity generation. Also, in the simulations here I compare different recycling methods for the same level of tax. Therefore the emissions quantities can vary. It would be interesting to extend this by looking at what carbon price levels would achieve the exact same aggregate emissions levels across the three recycling methods.

However, while a carbon tax will improve the environment by reducing emissions and therefore correcting an existing distortion, the introduction of the carbon tax will also have a distortionary effect in itself and so reduce welfare when measured in terms of economic output or employment. However, the carbon tax raises revenue which accrues to government and can be recycled into the economy somewhat or wholly offsetting the depressing effects of the carbon tax. In practice two important decisions will determine whether the negative economic effects of the carbon tax are offset and whether a double dividend of an improved environment and increased overall efficiency is achieved. These are how the tax revenues are recycled and the size of the tax base. When revenues are recycled they partially offset the negative GDP and employment effects compared to the no-recycling case. Therefore it is clear that an instrument that creates revenues is preferred to one which does not. This is why it is inefficient to allocate emissions permits freely which has been the case in the early phases of the EU ETS. In particular, where the revenues are used to reduce income tax then the reductions in macroeconomic variables are the smallest.

In this model recycling revenues through reductions in income tax levels is the most effective method of offsetting the negative effects of the carbon tax and therefore provides the greatest potential to achieve a double dividend. The method of recycling is therefore extremely important as to the general equilibrium effects of the tax. Therefore, depending on how revenues are used, policymakers may be able to offset some, or all, of the negative effects of the tax on economic activity. However, the UKENVI model employed in these simulations is not able to achieve a double dividend in the UK in 2020 under any of the methods of recycling for a carbon tax of £22. However, results from a similar model for Scotland by Allan *et al* (2012) has suggested that a double dividend is possible for Scotland, when revenues are recycled through reductions in income tax, but the level of the tax is significantly higher at around £50. The difference between results in Scotland and the whole UK may be explained by the fact that electricity generation is a much larger part of the Scottish economy and also differences in assumptions regarding the openness of the economy are relevant. Further modelling research, perhaps using a multi-regional model of the UK, could perhaps shed more light on these differences. It is also important to note that regions with lower prices in non-fossil fuel energy i.e. Scotland, will stimulate exports to the region where prices are higher i.e. England.

It may be the case the revenues are used to achieve more specific goals than simple general reductions in income tax. The Government may wish to set aside revenues to help protect the competitiveness of industries which are affected by the carbon tax such as cement or iron and steel. The revenues could also be used to pay for subsidies for renewable energy technologies. In fact an important omission from the above analysis that is not incorporated into the model is the effect that the tax will have on innovation of low-carbon technologies which would make easier the achievement of emissions reductions at a lower cost. Several other models have attempted to incorporate incentives to innovate and learning-by-doing into CGE models.[119]

[119] See Kahouli-Brahmi (2008) for an overview.

It is also apparent from the sensitivity analysis of the model that elasticity of substitution between intermediate inputs is important for the dynamics of how the economy reacts to the carbon tax. For instance, varying assumptions in order to make substitution between electricity generating technologies more elastic will make it easier to achieve emissions reductions but makes achieving a double dividend more difficult. Assumptions regarding the elasticity of the labour market too will determine whether employment is increased or reduced from a carbon tax. It is beneficial to compare the baseline scenario results with other assumptions about how flexible the labour market operates. In the above analysis the fixed real wage scenario makes the negative economic effects of the carbon tax much more prominent. The fixed real wage means that employment tends to take the negative impact of the carbon tax as wages cannot adjust after the tax. Therefore the flexibility of the UK labour market in response to a carbon tax would be important in practice. A future extension of this work would therefore be to systematically explore what conditions and assumptions give rise to a double dividend.

One way of ensuring that targets are achieved and that the tax rate is not manipulated for political purposes would be the approach discussed in Chapter 2. That is, to delegate the setting of the tax rate to the independent Committee on Climate Change. This would ensure that the rate was credible over time and would not be altered to achieve other political goals e.g. lowered by government to stimulate economic output. However, as discussed previously, it is unlikely control of a tax would be delegated because the tax would raise substantial revenue which the Treasury would want to control. Also, in practice, given that many governments, including the UK, face a budget deficit, then revenues may be used to reduce the current deficit rather than being used to reduce an existing distortionary tax.

The modelling undertaken in Chapter 5 does have limitations in the way in which certain practical problems are dealt with but it must be emphasised that these results are highly simplified. For instance, there will be limitations in practice on the capacity of new technologies, such as onshore wind or inputs into biomass, but these concerns are not captured in the UKENVI model. Also, in practice the capital stock of electricity generating technologies will often be fixed for longer than one period, as in the model, and so future simulations should attempt to incorporate the fixed nature of capital in greater detail. The notion of ‘capital flight’, where capital moves from the region where a tax is imposed to a region where it is not imposed, is also not considered within this framework. However, while this may be relevant in practice for a few sectors which are exposed to international competition, given the nature of electricity generation this will not be an issue for this sector.

Chapter 6

Conclusions and further extensions

1. SUMMARY AND CONTRIBUTION

As international action on climate change has proven difficult to achieve, and no substantial progress has been made over the last two decades despite international conferences and agreements, the policy and actions of individual nations with respect to climate change are becoming increasingly important. The UK is at the forefront of climate change policy from a “domestic” perspective as the first nation to introduce a legally binding framework, the Climate Change Act (2008). The UK Government has a legally binding commitment to reduce GHG emissions by 80% by 2050. The Act also creates five-year carbon budgets which will determine the path of emissions reductions up to 2050 and requires a minimum reduction by 2020 of 34% from 1990 levels. To achieve its climate change policy goals the government has a number of policy instruments including institutional reform and market mechanisms. The objective of this thesis is to contribute to a discussion and analysis of the main approaches taken by the UK Government in respect to climate change over the previous five years. The approaches adopted and lessons learnt in the UK since 2008 can be used by many other nations as they begin to adopt their own policies on tackling climate change.

In Chapter 1 I give a background to the climate change discussion and motivate the research of the thesis. In Chapter 2 I analyse the role and remit of the Committee on Climate Change which was introduced as part of the Climate Change Act (2008). I discuss a number of reasons why this body may have been created including: provision of independent climate change information and statistics; an advisory capacity to recommend appropriate policy to government; a monitoring function to achieve government goals, and delegation of the task of achieving the Government’s climate change policy goals, or indeed a combination of all of these reasons. I argue that the CCC's original conception appears to be rooted in overcoming the issue of time inconsistency in carbon policy first put forward in Helm (2003). There exists a time inconsistency problem in that there is underinvestment in low-carbon energy sources needed to reduce emissions because government policy is not credible over the lifetime of the investment. I describe the composition of the CCC in practice and then compare the CCC against another body which is intended to overcome a time inconsistency problem, the Monetary Policy Committee of the Bank of England. There are numerous differences between the two bodies including time scale and uncertainty of the time-inconsistency problem, the breadth of their remits, and whether other institutional bodies exist in their field. In particular the most striking difference between the two bodies is that while the MPC has a policy instrument to achieve a specific target which is set by government, the CCC advises on the setting of a target which the government itself achieves. In practice the CCC is an independent body which advises government on their carbon budgets and monitors government progress on the achievement towards these budgets. I argue that this is similar to the original work of Stern (2006) but on a continuing basis which allows for the regular updating of information and a more in-depth analysis. It is also enshrined in legislation making it a unique and important institution in relation to national climate change policy and its independence and credibility are fundamental to the success of the UK's climate change framework. I conclude by stating that one specific method of strengthening the CCC, by delegating it more powers which would make it more akin to the MPC, would be to give it control of a policy instrument with which to achieve the carbon budgets. This would mostly likely take the form of a carbon tax, which it could set at a rate designed to achieve the emissions reductions required to meet the carbon budgets, and thus overcome the time-inconsistency problem.

There is also an evaluation of the CCC in Chapter 2 which discusses the setting of carbon budgets when there are many external factors which will determine whether it is possible to achieve, such as economic circumstances and the EU ETS price. The CCC have been aware of these factors and explicitly considered for example, how the effects of the recent recession should be incorporated into the carbon budgets. There is also a general discussion on issues such as what legally binding targets actually means, the inclusion of international aviation and shipping, and the merits of production versus consumption-based emissions targets. The CCC also has wide-ranging extra considerations and I briefly discuss these as they often appear contradictory and involve various trade-offs. The monitoring functions of the CCC are described briefly. Finally there is a discussion of the interaction of UK climate change policy with other spatial policy levels and instruments, why harmonisation across policies is necessary, and the appropriate spatial scale at which climate change policy should be addressed.

I extend this debate on regional considerations further in Appendix B where I briefly look at the climate change policy of Scotland. I compare and contrast this regional policy framework with that of the UK and ask whether it is appropriate for Scotland to have their own policy with regards to climate change especially given that energy is a reserved matter. A comparison with the UK policy framework shows that Scotland has stricter targets in terms of both the size of the emissions cuts as well as the frequency of targets. I argue that the annual targets that the Scottish Government have adopted limits flexibility too much, especially given that emissions are often outwith the direct control of the Scottish Government. An important note is that extra emissions reductions made through increased use of renewables will have no effect in terms of climate change because emissions from electricity combustion in Scotland are included in the EU ETS traded sector. Any emissions reductions made will allow for permits to be sold to other installations in the EU who can emit. The "no new nuclear" policy of the Scottish Government obviously does not assist in the achievement of emissions targets and only limits the options available. There will be a referendum on Scottish independence in 2014 and either full independence or extended devolution would provide fiscal autonomy for Scotland and greater policy instruments to achieve climate change goals. Allan *et al* (2012) have used a CGE model of Scotland to simulate a carbon tax on the Scottish economy assuming that such revenue raising powers then reside in Scotland and find that a double dividend is possible where revenues are recycled through reductions in income tax.

Through an analysis of recent institutional and legislative measures I believe the first part of the thesis research provides a valuable contribution to the ongoing evaluation of climate change policy in the UK in terms of evaluating institutional arrangements and regional considerations.

The remainder of the PhD thesis then concentrates on the idea that a new policy instrument may be used in the UK to achieve climate change targets and in particular the use of a carbon tax to achieve emission reductions which was a conclusion from Chapter 2. I intended to create a model which could simulate the effects of climate change policy instruments at the UK level and therefore assist policy makers by showing the likely economic effects of such policies. However, before I could do so there were a number of database developments that needed to be pursued.

In Chapter 3 I consider the EU ETS, which is the largest single policy instrument on climate change. Just under half of all the UK's carbon dioxide emissions are covered by this policy. Therefore it seemed appropriate that any database and model should identify the sectors covered by this scheme and undertaking this would be useful for model aggregation at a later stage. However, there are several difficulties in matching the EU ETS coverage with the SIC sectors detailed in the IO table. Only combustion installations over a certain size are required to hold a permit. Those installations with a capacity over 20MW are part of the scheme but installations with a smaller capacity are not. Once the relevant sectors were identified I carried out an energy-economy-environmental IO analysis which distinguished between the "traded" and "non-traded" sectors of the EU ETS. These results highlighted the importance of electricity generation as a major contributor to emissions in the UK. It therefore became apparent that for the multi-sector general equilibrium models, needed to analyse the effects of climate change policies on the economy, there must be a richer level of data on the electricity sector.

A major limitation of using an input-output database as the basis of an IO model considering energy and environmental policy issues is that the electricity sector is typically treated as a unified sector in the economic accounts, whereas in practice there are wholesale markets, transmission, distribution and generation, all of which make up this sector. Given that there are considerable substitution possibilities within that sector then it is essential for energy-environment modelling that a variety of electricity generating technologies of radically differing emissions-intensities are separately identified e.g. large combustion coal plants and onshore windfarms. Therefore in Chapter 4 I disaggregate the electricity sector. Data limitations made this particularly difficult but previous work by Gay and Proops (1993) and others helped inform an appropriate methodology. I then conducted the input-output multiplier analysis of Chapter 3 but with a disaggregated electricity sector. These results showed that fossil-fuel, and in particular coal, electricity generation was the most significant contributor to emissions of carbon dioxide in the UK.

A limitation of employing the input-output modelling technique used in Chapters 3 and 4 is that it assumes a passive supply-side and therefore, strictly, only demand changes can be modelled. A further issue is that IO modelling assumes inflexible technology, particularly in modelling emissions which must be linked to output. Therefore the only method available to reduce emissions is a reduction in output. To overcome these limitations in the next chapter I use a Computable General Equilibrium (CGE) model of the UK economy which allows for simulations of supply-side policy shocks and linking of emissions to inputs.

In Chapter 5 I discuss and model a major policy instrument open to the UK to meet its carbon budgets: a carbon tax. Given the previous conclusion from Chapter 2, which suggests giving control of a carbon tax to the CCC, I consider the effects of a carbon tax used to meet the emissions reduction target of a 35% reduction in CO_2 emissions by 2020 from 2004 levels.

The chapter begins with a discussion of the theory of externalities and how price and quantity mechanisms can be used to overcome them. I then discuss the advantages and disadvantages of using a carbon tax. One particularly interesting possibility for policy-makers is that introducing a carbon tax may lead to the potential existence of a double dividend of reduced carbon emissions combined with improved welfare or employment relative to the original equilibrium level. There is a further discussion about what constitutes a double dividend and how and when they may occur. The application of a carbon tax in the UK seems appropriate given the history of the Climate Change Levy and recent decision to amend exemptions of the levy into a carbon price floor which will underpin the EU ETS price to stabilise the price of carbon in the UK. It seems that the UK will introduce the carbon floor rates to stabilise the EU ETS price in the UK and thus create a hybrid policy instrument. However, this will not actually affect the overall world emissions level which contributes to climate change because any emissions saved in the UK can then be produced elsewhere in the EU. It will only help to provide certainty for investors and to achieve UK carbon targets.

In Chapter 5 I also conduct a literature review of several national CGE models which have examined the impact of various carbon taxes. The comparison of their findings reveals that a number of aspects appear to be important in determining the effects of a carbon tax and whether a double dividend is possible. The idiosyncrasies of the database in terms of each nation and the baseline year chosen will be important to results as will the treatment of the labour market and assumptions regarding elasticities of substitution between key parts of the nested production functions. A crucial factor as to whether a double dividend is achieved is whether and how revenues from the tax are recycled into the economy.

The results of the carbon tax simulations undertaken in this chapter show that for the UK it is possible to meet emissions reduction targets and to identify the effects that this is likely to have on the economy generally and individual sectors. The carbon tax will incentivise emissions-intensive sectors to alter their inputs where possible and where it is not they will reduce their output. This is often the case for the EU ETS “traded” sectors that are identified in the model. There will be significant substitution between electricity generation away from gas and particularly coal generation towards low-carbon technologies. Labour-intensive sectors such as Services industry will be the least affected and may see increases in employment where labour can substitute for energy. The chapter also shows that by recycling revenues from the carbon tax through reductions in income tax, which will stimulate household spending, it is possible to partially offset the reductions in output and employment that would otherwise occur.

Hopefully the analysis undertaken with respect to the carbon tax in this thesis can be of use to policy-makers who are considering methods to achieve emissions reductions in the UK and what effects that these may have. The results should also show that it is important how the revenues of any environmental taxes are used and this is especially important at a time where austerity measures are being introduced and ways of raising extra revenue are needed. There is also now a model which can be used and developed further to consider environmental problems in the UK and how this analysis could be expanded upon.

2. FURTHER EXTENSIONS

There are several aspects of the research which could be updated or extended further. It will be interesting to see the development of UK and also Scottish climate change policy over the coming years. How will the CCC develop as an institution over time and will it serve as an example for other nations wishing to limit their own emissions unilaterally? Or will it become an example of failed institutional reform because it was not granted enough powers? Also, will Scottish climate change policy continue to evolve and move further away from UK policy, particularly in light of the referendum on independence in 2014 or possibly increased devolved powers? To answer both of these questions it will be essential in the future to monitor carefully the records on delivering the UK carbon budgets and the annual Scottish climate change targets. An exploration of consumption accounting of emissions in the UK would be beneficial as it is necessary to ask whether production-based emissions reduction targets are really appropriate when emissions-intensive goods can be simply imported.

A contribution of this thesis is the creation of this particular formulation of the UKENVI model which can now be used as a basis to explore UK environmental policy issues in greater detail. However, further work is required on the database regarding the EU ETS and the disaggregation and treatment of the electricity sector.

The consideration of the EU ETS in the model is fairly simplistic in that it identifies aggregate sectors which are then included as a "traded" sector. As mentioned in the thesis the coverage of sectors is not completely accurate in our model as simplifying assumptions are made and other approaches towards modelling the EU ETS are possible. These could be explored further but there is a trade-off here between richness of data in the simulations and simplicity of modelling. It may also be possible in future to incorporate emissions trading into the model simulations although its impact can be simulated with the current model. Also, to truly capture the effects of the EU ETS it would be necessary to construct a CGE model at the EU level. This may include many EU countries or simply have UK and the rest of EU inter-regional model.

A survey from UK electricity companies could be collected to better inform the data on sales and purchases from electricity generating technologies. More detailed data on purchases by electricity generators is essential and, in particular, distinguishing between one-off capital costs and regular variable costs is necessary. There is currently not enough information on newer technologies where data may be limited. This is a difficult area to collect given that many companies will simultaneously be generators and suppliers of electricity and also given sensitivity of private information, particularly among newer technologies who may not wish to disclose their expenditure and revenue data for competition reasons. It would be in the interest of all users of the accounts and all users of descriptive IO and CGE e.g. governments, researchers, to use their resources together in order to create database capable of satisfy the data requirements. A detailed survey would need the backing of major UK electricity and energy companies and could be organised and funded together by the appropriate departments in the UK Government and devolved administrations to ensure compatibility with official data sources.

One obvious extension to the modelling which was undertaken would be to consider GHGs as a whole in order to give a fuller account of UK emissions which cause climate change. In the simulations in Chapter 5 I only consider carbon dioxide. While CO_2 is the largest GHG emitted in the UK we must not forget that several other GHGs are more harmful to the atmosphere and although lower in aggregate they have a greater global warming potential. Methane gas is a large by-product of the process of the agricultural and waste sectors. Nitrous Oxide is also heavily emitted by agriculture and the manufacture of petrochemicals. Therefore it is essential that other GHGs are incorporated into the environmental side of the model. The data on emissions per sector for these gases, such as methane and nitrous oxide, is available. However, they are less easy to link with inputs in the model and have tended to be modelled through coefficients linking them with output. This means that in order to reduce their emissions reductions of output are required from the sectors which produce these GHGs, which is far from efficient. Further research into how these other GHG gases have been modelled previously is necessary and an investigation into how technology changes could be incorporated into the model is needed.

Additional work could be undertaken to incorporate endogenous technological change into the model. At the moment there is no rate of technological change in these simulations and thus this limits emissions reduction possibilities. In practice it should be easier to reduce emissions in the future as we would expect technological improvements to be important and to be linked to the price of carbon i.e. endogenous. As abatement processes improve over time and therefore allow for greater emissions reductions from the same input combination. It is important to extend the model to capture technological learning. The technological learning concept assumes that technologies performance improves as experience of the technology accumulates through increased adoption. This has been implemented in other energy system models predominantly through learning curves which show the relationship between cost decrease and output production growth (Kahouli-Brahmi, 2008). Research by Tamba (2012) is seeking to incorporate endogenous technological change and learning rates into a CGE model for Scotland and could be extend into this UKENVI model.

With regards to the double dividend hypothesis, the idea is always thought of in terms of two entirely separate dividends, one environmental and the other economic. The second dividend is purely considered as the economic outcome regardless of the impact of the environmental improvement and the fact that it may benefit individuals and even allow for greater economic improvements in the future. Often the first dividend is assumed not to play a role in utility or the ability to achieve economic goals. It may therefore be beneficial to attempt to think about the double dividend hypothesis differently and attempt to explicitly model the environmental improvement aspect directly in the utility function as considered in Schwartz and Repetto (2000).

Another consideration for extending this research would be to use a database which is updated to a more recent year. The use of 2004 as an equilibrium year is limited particularly in relation to the EU ETS and electricity sector. The development of the renewables industry which has become considerably more prominent as a form of electricity generation in the UK is not accounted for in the baseline year. A database which is closer to the present year would be favourable for modelling traded sectors especially given that the EU ETS was not in force until 2005 and so the database will not include any of their spending on, or sales of, emissions permits. If a more up-to-date IO database becomes available this could be used however it is important to note that that several years may provide their own problems given that the EU ETS price varied significantly during Phase 1 (2005-2007) and also the recession in 2008 means that many recent years may not be the best examples of an economy in equilibrium for the UK.

Also, a more rigorous sensitivity analysis of this UKENVI model formulation could be undertaken in order to ensure parameter values are suitable. Given that there is no consensus on exactly how energy use should be incorporated in CGE models then the treatment of energy in this UKENVI model, and where it should enter in the production structure, could also be analysed through different production structures and results compared to test the importance of these assumptions. Although I do a sensitivity analysis to some extent in Chapter 5 of this thesis, it is not possible to check all features of the model due to time constraints. A more rigorous sensitivity analysis could be undertaken in future.

There are other policy institutions and instruments in the UK which could be analysed and scrutinised in further detail. There are other forms of recycling revenues from the carbon tax which could be simulated such as reductions in social security contributions of employers or government spending specifically on domestic low-carbon technologies including subsidies on renewable electricity generation.

Given the disaggregation of the electricity sector conduct in the thesis, this UKENVI model formulation allows consideration of demand and supply side effects of policy shocks on the EU ETS "traded" sector. The most obvious extension of this thesis would be to apply the carbon tax to only the sectors considered covered by the EU ETS. Only time constraints with regards to adapting the model prevented these simulations being undertaken. Also, a carbon tax that is only applied to the "non-traded" sectors may be appropriate as they are not covered by a market mechanism at present. However, it is unlikely that this would be particularly effective (the most emissions-intensive sectors are the "traded" sectors) and would be difficult to implement and measure in practice. Therefore other instruments aimed at reducing carbon and other GHG emissions in the non-traded sector may be necessary to develop instead. The disaggregation also allows for demand stimulus to the various renewable electricity generation technologies such as undertaken in Gilmartin (2010).

One specific simulation of interest would be to model the possible effects of the carbon price floor in the UK. This could be achieved by a tax on sales of fuel to electricity generation sectors at a level given for the carbon price support rates and increasing them over time as intended. It may be possible to do this simultaneously with an exogenous EU ETS price of the amount predicted in practice. This would obviously achieve significantly less emissions reductions and generate less revenue than an all encompassing carbon tax but it would be interesting to observe what the predicted system-wide effects of this new policy would be.

This formulation of the model does not currently capture the rigidity of capital in some sectors such as electricity where capital is fixed for a number of years. This could be achieved through a more detailed specification of the supply-side technologies in the energy sector. This may be achieved by combining with another model. There may also be a case for fixed-factors to be incorporated into the model and further investigation into whether or not this would be beneficial should be undertaken.

The development of new regional energy-environment-economy models may be appropriate to develop given the number of devolved governments in the UK who are pursuing their own environmental interests and the increasing pressure for further devolved powers. Similarly an inter-regional UK model would be interesting to consider the distributional effects of a carbon tax.

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Appendix A

Chapter 2

Table A1: Advisory areas of Committee on Climate Change

Task	**Details**	**Recommendation**
The 2050 UK target emissions level	The CCC provides a recommendation on the appropriate long-run emissions level for the UK. This process requires scientific judgements as well as taking into account burden-sharing methodologies, international agreements and a technology vision for the UK. The basis for these decisions is made public in order to give transparency to the process	The 2050 UK target is an 80% reduction below 1990 emissions levels. This is an increase from the government's previous 60% target (DTI, 2007) and was adopted in response to updated scientific evidence on the potential impacts of climate change, and also the realisation that recent concentrations of GHGs have proved to be higher than previously thought.
Five-year carbon budgets	The CCC also recommend to government medium term reductions in the form of 5-year carbon budgets which assist in achieving credibility, compared to the alternative of having a single, long-term target for 2050. There is a legally binding requirement that the 2018-22 GHG budget must be 26% below the 1990 emissions level. The CCC has set out a trajectory for the first four budgets	In their first report, the CCC proposed an "Interim Budget" of a 34% reduction in emissions by 2020 compared to 1990 levels, which should apply if no global deal is reached. They have stated however, that if a global deal is reached, a more stringent "Intended Budget", of a 42% reduction should apply to the UK by 2020, as more reductions could be achieved through tightening of the EU ETS allocation (CCC, 2008).

Within these budgets the relative contribution of EU ETS traded versus non-traded sectors needs to be identified	Currently around 48% of the UK's carbon emissions are covered by the EU ETS (DECC, 2009). The CCC must consider the relative split in the budgets between those sectors covered by emissions trading and those not covered under any trading scheme, which are likely to require different policy solutions.	The CCC has split it targets out into traded (covered by EU ETS) and non-traded (uncovered) sector when they are setting the carbon budgets and highlights possible policies for each.
The inclusion of international shipping and aviation	The CCC must analyse how important the inclusion of shipping and aviation is in lowering UK emissions, how much these sectors should contribute, as well as the practicality, methodology and timing of their inclusion.	The CCC produced an Aviation report (CCC, 2009b) In its 4th Carbon Budget report the CCC have recommend incorporating international aviation and shipping into future budgets and will be considering further how this should be done (CCC, 2010b).
Whether to include all GHGs in the above budgets	Given that Kyoto commitments relate to GHGs as a whole, but the EU ETS covers CO_2, there seems to be a need to decide on the precise definition of emissions for the purposes of the CCC budgets.	The CCC initial report decided that all GHGs should be part of the budgets and targets because: all GHGs contribute to climate change; the UK's Kyoto commitments are listed in terms of GHGs, and the inclusion of more gases allows greater flexibility in achieving targets.
Extent of reliance on credits used to achieve budgets	Recommendations must be given on whether credits from Kyoto flexible mechanisms such as Certified Emissions Reductions (CERs) from the Clean Development Mechanism (CDM) should be purchased in order to achieve the domestic emission reduction targets by cutting emissions in developing countries with lower abatement costs.	The CCC suggested that no credits should be purchased under the Interim budget and the government has agreed to follow this recommendation.

Table A2: Extra Considerations of Committee on Climate Change

Competitiveness	The CCC must consider which industries are potentially at risk, what policy regimes might affect marginal costs, the scale of possible effects and how these can be combated.
Fuel Poverty	The CCC models the impact of carbon budgets on different households with particular concern for lower income households and look at what present and possible policies may be appropriate to reduce the negative effects that carbon budgets may have.
Fiscal resources	This should take auctioning of allowances and environmental taxes into account, which can be used for revenue recycling. Also there are fiscal implications for government expenditure of possibly purchasing Kyoto credits to meet targets. More generally they must also consider whether taxed activities will change in volume and whether alternative fiscal instruments are required to achieve goals.
Security of Supply	This mostly concerns the risks attached to different energy forms and combinations as well as the capacity of the electricity grid and supply to meet energy demands.
Regional effects	The CCC disaggregates their budgets for the main regions of the UK and look at non-traded sectors for devolved authorities which have their own policy mechanisms. The CCC produced a report for the Scottish Government (CCC, 2010a) advising on Scottish specific climate change targets.

Appendix B[120]

An overview of Scottish climate change policy

1. Introduction

Despite much of energy policy being a reserved issue for the UK Government, Scotland has pursued its own distinctive energy policy (Allan *et al*, 2008), particularly in relation to climate change. The Climate Change (Scotland) Act was passed in 2009 and outlines Scotland's commitment to tackling climate change. It requires Scottish greenhouse gas (GHG) emissions in 2050 to be 80% less than their 1990 levels, with an interim target of a 42% reduction by 2020.

Climate change is an international problem which appears to require a global solution and it is therefore not clear that the appropriate spatial scale for policy action is the regional or even national level. The Scottish Government is aware of this, but claims that such emissions' reduction targets can be used as a means of supporting the UK's international commitments and also showing leadership to encourage other nations to tackle climate change. However, Scottish climate change policy must also be considered in the context of Scottish energy policy as a whole. The Scottish Government has other energy policy goals, notably security of supply, affordability and economic growth through the development of low carbon technologies, notably renewables.

This research is intended to provide a brief overview of the main issues involved in Scottish climate change policy. I give a brief background, in Section 2, on international, EU and UK climate change policy. In Section 3 I provide an overview of the main features of the Scottish Climate Change Act and highlight particular differences with the UK equivalent framework. In Section 4 I discuss the issues surrounding low carbon technologies and their impact on climate change policy in

[120] This work was published in the *Fraser of Allander Economic Commentary*, Special edition on Energy and Pollution, January 2011, pp. 27-34

Scotland. I consider the policy instruments available to the Scottish Government while functioning within EU and UK frameworks in Section 5. In Section 6 I conclude and identify avenues for future research.

2. Background on International, EU and UK policy

Given the global nature of the climate change issue, most initial policy effort has been on international or multi-national levels, like the EU. There has also been considerable effort at the UK level. Scottish climate change policy is heavily influenced by and conditional upon policies at these other spatial levels. This section therefore gives a short summary of the main agreements, policies, instruments and legislation that affect Scotland.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) is an international agreement that imposes reduction targets on GHG emissions for developed nations. It was established in 1997, ratified in 2005 and runs from 2008-2012. No legally binding successor agreement has yet been agreed, although the informal Copenhagen Accord was adopted in 2009 as a step towards this. Kyoto allows countries to use various, specifically created, flexible market mechanisms in meeting their emissions reduction commitments. These are International Emissions Trading, Joint Implementation (JI), and the Clean Development Mechanism (CDM).[121] In theory all these mechanisms should allow emissions abatement to take place in the most cost effective manner i.e. where it is cheapest, and also allow for the diffusion of low-carbon technologies to developing countries.

[121] Emissions Trading allows for the trading of allowances designated to countries under Kyoto. These are called Assigned amount Units (AAUs). JI allows for emissions reduction projects to be undertaken in other developed countries which also have commitments under Kyoto and any reductions produce Emissions Reduction Units (ERUs) which can be used to meet Kyoto commitments. The CDM is similar to JI but allows for emissions to be offset through projects in countries which do not have reduction targets under Kyoto, mostly developing nations. The credits are awarded for any “additional” reductions made beyond a hypothetical baseline scenario. In the CDM these are Certified Emissions Reductions (CERs).

Under the Kyoto Protocol, the EU-15 countries have a bubble which allows them to achieve together an overall target of an 8% reduction in emissions by 2012. In order to achieve this reduction the EU created its own instrument in the form of an emissions trading scheme, the EU ETS, in 2005. The EU ETS is a 'cap and trade' system where a limit is put on total emissions based on Kyoto commitments and the scheme allows CO_2 allowances, called European Union Allowances (EUAs), to be bought and sold between operators in certain emitting sectors.[122] The sectors currently covered are: energy, ferrous metals, minerals, pulp and paper. Each EUA is equivalent to one tonne of CO_2. All installations within these sectors require a permit to operate which covers almost half of EU carbon emissions. However the allocation of the tradable EUAs to permit holders is initiated at national level with individual Member States submitting National Allocation Plans (NAPs) to the EU Commission for approval on the distribution of allowances and details of all installations covered. Phase I of the EU ETS ran from 2005-2007 and Phase II runs in parallel with Kyoto from 2008-2012.

In 2008 the EU introduced its 20-20-20 targets for 2020. This EU goal requires that by the year 2020 there will be a 20% reduction in GHG emissions, to have 20% of final energy consumption met from renewables[123] and a 20% reduction in energy consumption through promoting energy efficiency. The EU stated that it would increase its emissions reduction commitment from 20% to 30% if an international successor to Kyoto was agreed and other countries adopted strict targets. Although there is an EU renewables target, there is no EU-wide renewables policy instrument and each member state have their own renewables target and can meet it by whatever method they deem appropriate.

The Climate Change Act 2008 outlines the UK's contribution to tackling climate change by setting UK emissions targets for 2020 and 2050. The Climate Change Act also created the Committee on Climate Change, an independent body tasked with

[122] Note that this is only carbon dioxide and not all GHGs that are traded.
[123] Note that this is total energy consumption coming from renewable sources including heat and transport. It is therefore likely that electricity generated from renewable sources will need to be substantially larger than 20% in order to make this target.

advising the UK Government on setting its emissions targets, including 5-year carbon budgets, and monitoring government progress towards the targets. The UK emissions reduction target for 2050 of 80% is the same as that for Scotland[124] but the 2020 target is dependent upon a global climate change agreement being struck. If such an international deal is agreed, then the EU will raise its own emissions reduction targets (from 20% to 30%) and thus the EU Emissions Trading Scheme (EU ETS) cap will be tightened. This will require greater reductions from UK installations covered by the EU ETS i.e. the traded sector, which includes electricity generation. Therefore the UK Government has set a 2020 "interim target" of a 34% reduction but this will rise to 42% "intended target" if international and EU policies dictate so.[125] The overall UK target in 2020 is therefore conditional upon the EU target which is in turn dependent upon a global deal. This framework shows that the UK is willing to demonstrate leadership with its initial effort but that it will also commit to higher targets if others are willing to make more significant reductions.

> "This leadership argument is best understood in game theory terms: it is an attempt to induce steps towards a global carbon cartel to reduce the quantity of emissions."[126]

It is also worth stating that the UK has adopted a renewable energy target of 15% by 2020 as its contribution towards the wider EU renewables target.

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[124] Initially the UK target was a 60% reduction by 2050. This was updated in 2008 to 80% based upon the advice of the Committee on Climate Change. This increase was adopted in response to updated scientific evidence on the potential impacts of climate change, and also the realisation that recent concentrations of GHGs have proved to be higher than previously thought.
[125] The difference between these targets is roughly 465 MtCO2e which will be met by a combination of increased traded and non-traded sector effort.
[126] Helm (2007c)

3. Scottish Climate Change Act

3.1 Strict targets

The Climate Change (Scotland) Act sets a 2020 target which is more ambitious than the UK equivalent. Scotland has legislated for a 42% reduction in emissions regardless of what occurs at any other spatial level.[127] Such ambition may be laudable in principle but it must be informed by, and be consistent with, EU and UK policy and account for the likely impact of these other spatial levels. This therefore raises the question of whether it is possible for Scotland to meet the 42% target, especially if there is no global deal.

The advice from the Committee on Climate Change (CCC) is that achieving the 42% target is possible but the CCC recommends setting separate targets for the 'traded' and 'non-traded' sectors in Scotland. The traded sector emissions will be counted as Scotland's share of the UK allocation in the EU ETS (CCC, 2010a). This is in the spirit of the EU ETS, where the geographic distribution of emission reductions simply reflects the least-cost locations for meeting the overall cap. However, it also implies that, from a purely Scottish perspective, any extra reduction in traded sector emissions, for example, associated with the expansion of renewable electricity generation, will not count towards meeting the reduction targets.[128] This accounting methodology also implies that any non-CO_2 GHGs produced within the traded sector, such as methane, will not be counted as Scottish emissions.[129]

As for the non-traded sector, the CCC predicts that, with no global deal, there would have to be a 47% reduction in non-traded sector emissions to meet the overall Scottish target of 42%.With a global deal the non-traded sector target falls to 39%.[130] It seems perverse that the non-traded target shrinks if a global deal is agreed. The

[127] Although the Act does allow for modification of the target based upon advice from a relevant body. This body is the UK Committee on Climate Change unless a Scottish equivalent body is introduced.
[128] It is likely, however, that Scotland's share of traded sector emissions may diminish over time.
[129] The traded sector consists of highly CO_2-intensive industries and non-CO2 emissions from the traded sector are on the whole minimal.
[130] See (CCC, 2010a) Table 4.1 for calculations

CCC therefore suggests making Scotland's non-traded target invariant to the achievement of a global deal. This seems logical because if Scotland wishes to make its framework invariant to international agreements, then at least one target, the non-traded sector, must be made invariant to reduce uncertainty. Given that Scotland is part of the EU ETS, there is nothing that can be done to make the overall target invariant.

3.2 Annual targets

The Climate Change (Scotland) Act has established the requirement of yearly carbon budgets in Scotland. It will be interesting to see how these are set and met in comparison to the UK budgets, which are set for 5-year periods. The annual Scottish targets for 2011- 2022 are shown in Figure B.1.

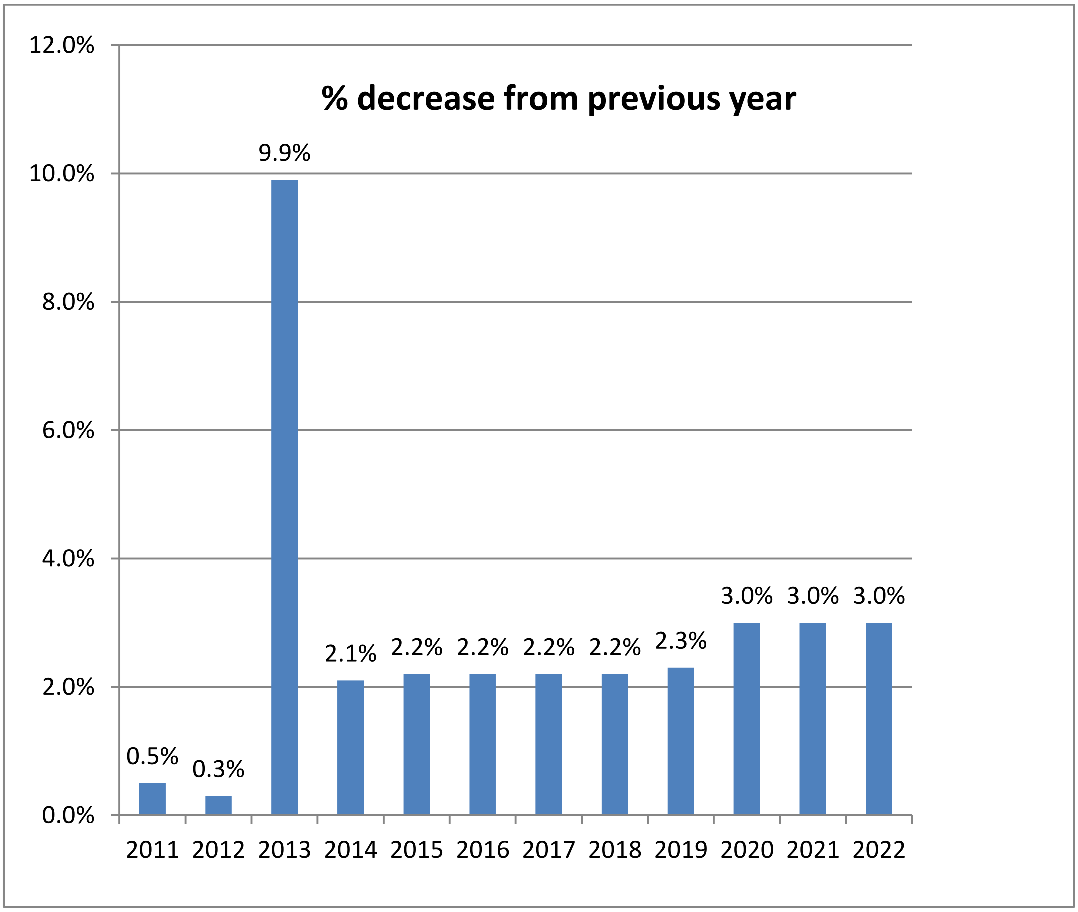
The frequency with which budgets are set reflects a trade-off between certainty in the future emissions path and flexibility in meeting targets. Annual year-on-year targets provide certainty for investors, provided that there is confidence that these targets will be met. However, setting 5-year budgets allows for the benefits of flexibility in response to uncontrollable events and a lower reporting burden.

Of course annual targets do not necessarily imply certainty; increased frequency may make it more difficult consistently to achieve targets. For example, if a nuclear station had to shut one year unexpectedly then other types of electricity generation, most likely coal and gas, would need to make up the difference and thus emissions would substantially increase for that single year. This issue is especially important given Scotland's current dependence on a small number of large generators.[131] Less frequent budgets would allow Scotland to cope better with these unexpected fluctuations. The CCC's report to the Scottish government (CCC, 2010a) has expressed concern with the lack of flexibility in the Scottish annual targets and suggests measures could be considered to increase flexibility, although it is not within the CCC's remit actually to recommend doing so.

[131] See Allan et al (2010a)

An issue with setting 5-year budgets is defining exactly how the budgets are expressed because the stock of carbon in the atmosphere is more important for global warming than the flow. For example, meeting the 5 year target by a large reduction in the final year will leave more carbon in the atmosphere, and cause more global warming, than a gradual reduction.

Figure B.1: Annual Scottish emissions reduction targets



Source: http://www.scotland.gov.uk/News/Releases/2010/09/22133935

Targets for 2011 and 2012 are relatively small reductions, most likely due to the recession but from 2014 onwards there is a 2-3% decrease in emissions year on year. There is a substantial one-off increase in emissions reductions in 2013 (9.9% relative to the previous year) due to the beginning of the third phase of the EU ETS and therefore the expected tightening of Scotland's allocation in the traded sector. The Act requires reductions from 2020 to be at least 3% each year.

The Scottish annual targets were initially to be passed in secondary legislation in April 2010 but the first set of targets were rejected by a slight majority in the Scottish Parliament for not going far enough, as a pledge of annual 3% reductions each year was made in the SNP manifesto. A short-lived cross-party working group was then established to revisit these annual targets and suggest amendments. The targets shown above have been set out in the most recent Draft Order (not yet legally binding) laid before Parliament in September 2010. The first annual target for 2010 was found to be missed at the time of submission of this thesis with an increase in emissions of 1.9% from 2009 levels. This was blamed on extremely cold weather in 2010 and impacts of the recession in 2009 but regardless underlines the inability of annual targets to provide for real-life consequences.

3.3 Aviation and shipping

International aviation and shipping both cause considerable GHG emissions and so the Scottish framework explicitly includes international aviation and shipping in its emissions reduction targets. However, these are not yet included at the UK or EU level and there is no agreed method for accounting for these sector's emissions. The main question to ask is whether the Scottish Government can influence emissions in these sectors. If it cannot, then what are the implications of including them amongst the target reductions; and even if the Scottish Government can influence those emissions, would it be desirable to do so unilaterally?

There is likely to be considerable growth of emissions in international aviation and shipping, given previous trends. Therefore action on these sectors is imperative for tackling climate change. However, the ability to make significant reductions in these sectors is mostly outwith Scottish Government control unless it plans to severely limit travel and exports[132] Due to the international nature, the CCC do not attempt to

[132] We discuss policy instruments further in Section 5.

identify policies that the Scottish Government could use to reduce emissions in these sectors. Instead, given the growth trends in international aviation and shipping, the CCC (2010a) believes that GHG emission reductions of 44% will be necessary in the other sectors of the economy (i.e. the total economy less aviation and shipping) in order to meet the 42% Scottish target.

Even if it were possible for the Scottish Government to reduce its emissions from aviation and shipping, it seems inappropriate, given the international nature of these sectors, to include them in national targets before they are included on an international scale. Limiting emissions in these sectors before other countries could lead to serious competitiveness affects. Exactly how these sectors are included is also an issue because the production-orientated-nature of the targets makes it difficult to attribute emissions accurately. These sectors would lend themselves better to a consumption-based accounting methodology. It seems more likely that separate international sectoral agreements will be required in the long-run.

From 2012 domestic aviation will be part of the EU ETS traded sector and will therefore be outwith Scottish control for accounting purposes. A specific issue with the EU ETS is that it only targets CO2 and therefore misses many of the other greenhouse gases (GHGs) attributable to aviation which are included in the emissions reduction targets.

3.4 Banking and Borrowing

There is no banking or borrowing allowed between each year of the annual Scottish emissions budgets. Each yearly budget must be met, and any over-fulfilment cannot be carried over into future periods. This provides certainty in terms of targets but severely reduces the flexibility of meeting them, especially in years of significant variation in energy use and there is also no incentive to go beyond the necessary in reducing emissions in a given year. If targets are consistently met this may be very beneficial as the credible policy provides certainty to investors. However, if targets are frequently missed, in part because of their inflexibility, then the credibility of the annual targets will ultimately be undermined and perhaps the credibility of the government as a whole. If there are signs of this happening in practice then banking and borrowing should be considered as a means of allowing budgets to be met more flexibly between years. For example, annual targets cannot take into consideration outside events such as colder than anticipated winters, power generation shutting down or a *force majeure*, such as the limited air travel due to the volcanic ash in April 2010.

3.5 Use of credits

Purchase of credits may be used to help Scotland achieve its emissions reduction targets. These may be through the EU ETS or the various Kyoto mechanisms which are discussed in Section 2. As discussed already, there is no limit on the use of European Union Allowances (EUAs), as these can be freely traded within the EU ETS and will count towards Scotland's traded sector target. However, there is a limit on the "offset credits" purchased from the Kyoto flexible mechanisms such as JI or CDM. The Climate Change Scotland Act puts a limit of 20% on emissions reductions being made by purchased Kyoto credits which can be used to meet the non-traded sector target. This cap is set to ensure that the emissions reductions are met mainly through domestic measures.

Theoretically these flexible mechanism projects would achieve abatement at lowest cost. However, there are two concerns about their use. Firstly, extensive use of credits would not incentivise the necessary changes in the infrastructure of the economy to put the country on a path to making its 2050 reduction. This would leave us dependent upon reductions in other nations to make the target. Secondly, there are concerns that no significant reductions would be made if the use of Kyoto credits are not limited, as uncertainty exists about their true benefits. This scepticism is due to the difficulty in proving the 'additionality' of such projects against a hypothetical baseline scenario. If these projects are really not credible, then the whole process could be undermined.[133] Therefore domestic emissions reductions, which can be more accurately measured, are the preferred means of meeting the targets.

Given the lack of flexibility of annual targets and the absence of banking or borrowing, then purchasing credits may become important as a method of meeting Scottish targets in years of fluctuation in emissions. This may be expensive. The CCC (2010a) suggests credits may have to play a significant part in Scotland meeting its emissions reduction target, especially if there is no global deal. They estimate that a 20% emissions reduction commitment by the EU would require Scotland to purchase credits from the Kyoto mechanisms to cover a range of 9% to 17% of its reductions at an estimated cost of around £30million to £50million in 2020 in order to meet its emissions reduction targets. This is the most likely scenario but would fall within the 20% limit on credits set in the Climate Change Scotland Act and so would allow Scotland to meet its emissions reduction target. The amount of credits needed to contribute would be much less under the stricter 30% EU target, with up to 5% of the 2020 target being met by offset credits costing a maximum of £15 million (CCC, 2010a, p.42). Only time will tell if circumstances arise in which the Scottish Government must buy credits to meet their own self-imposed targets and if so, how they can justify this spending to the public

4 Low carbon technologies

As stated in Section 3, under the accounting principles of the Climate Change (Scotland) Act, low carbon technologies cannot contribute towards meeting emissions reduction targets at Scottish level. This is because the UK's emissions targets are bound to the EU ETS. Low carbon technologies cannot affect Scotland's performance in meeting its emission reduction targets because emissions from electricity production are covered by the EU ETS. In theory a policy instrument such as the EU ETS, which prices carbon, should achieve the necessary emissions reductions efficiently and thereby induce the desired level of investment in low carbon technolgies. Therefore having a renewables target (and corresponding

[133] See Hepburn (2007) for a review of the issues with Kyoto mechanisms

instrument, such as ROCs, discussed below), for example, only serve to raise costs and so prove inefficient. However, Sorrell and Sijm (2003) argue that, although additional policy instruments bring no efficiency gains, they can achieve other objectives such as stimulating investment in R&D where inducing initial investment is difficult because of moral hazard and imperfect information. In a Scottish context, renewables can be seen as contributing to other Government energy policy goals such as security of supply, and offering potential for economic development through the exploitation of low-carbon technologies.

Independently of the emissions reduction targets set out in the Climate Change Scotland Act, the Scottish Government has other policies and targets for the traded sector, in particular energy generation. The details and possible motivations of these policies are discussed below.

A ‘no new nuclear’ policy is held by the current Scottish Government with regards to Scotland’s energy portfolio.[134] This is especially important given that Scotland’s nuclear generating facilities are coming to the end of their life with Hunterston and Torness both scheduled to close (some 30% of Scotland’s electricity is currently generated by this source). Furthermore, a substantial proportion of coal-fired power plants are due to retire by 2016. The “no new nuclear” position is not enshrined in any legislation but reflects the stance of the two main political parties. This may partially reflect concerns of safety and disposal and also a perceived link between nuclear energy and nuclear weapons. In terms of climate change policy, a lack of nuclear capacity limits the options available for low-cost, low-carbon technologies available to replace emissions-intensive electricity generation. The UK government is pursuing nuclear within its future energy portfolio, and given the integration of the British electricity market, it will be the case that the costs of the UK government developing nuclear power will be distributed among all British electricity consumers, including those in Scotland (Bellingham, 2008).

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[134] Although strictly each application to generate electricity through nuclear would have to be considered on its merits, and only planning powers are available for the Scottish Government to stop new nuclear capacity.

It is not clear how Scotland will fill the energy supply gap but most likely this will be through the harnessing of various renewable energy sources[135]. In practice the energy gap will be met by market circumstances and investor decisions, however, the Scottish Government can indirectly attempt to influence the energy supply through its renewables policy. This is reflected in the fact that the Scottish Government has recently set a very demanding renewable electricity target of 80% for 2020 i.e. 80% of Scotland's electricity consumption must come from renewable sources.[136] The Scottish Government sees the potential benefit that renewables can have in terms of achieving energy policy goals, such as stimulating economic growth and promoting security of supply through diversity of generation sources. However, if the Scottish Government believes that renewables are contributing towards achieving Scottish climate change targets, they are misguided. Also, it is highly unlikely that strict climate change targets will do much in practice to help attract substantial investment in low-carbon technologies.

Regardless of these facts, the CCC believes there is still a need for low carbon generation, even if it is not part of the emissions targets, because "given that Scotland has an 80% target to reduce emissions, it is important not only that the traded sector cap is achieved, but that the way this is achieved is consistent with the longer-term path to an 80% emissions reduction in 2050 relative to 1990. Specifically, this path requires early decarbonisation of the power sector, and extension of low-carbon power to other sectors, namely through electric forms of transport and heat."[137] This reasoning appears to be based upon long-term R&D considerations. Towards 2050 there will be increased electricity requirements, for instance, through significant predicted increases in electric transport. During the next few decades, as we have already stated, there will also be retirement of many current power generators. It therefore makes no sense to provide this electricity from dirty generating sources if we are serious about reducing emissions. However, there is not a credible carbon price that extends this far into the future. Therefore there is a need

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[135] See Allan *et al* (2010a) for a detailed overview of the future for Scottish electricity supply.
[136] Note that this target is 80% of electricity and not all energy, which is the way the EU and UK renewables targets are expressed
[137] CCC (2010a) p. 27

to put significant research and development into renewables in order to provide a diverse, low-carbon power sector.

Meeting the 80% renewables target, while providing an adequate energy supply, will require tapping into the extensive renewable energy resources available in Scotland. A significant anticipated benefit is job creation in renewables and other "green" industries. This may also lead to Scotland becoming an exporter of renewable energy (Allan *et al*, 2007b) and possibly also an exporter of renewable technology itself and its operative and management experience (Allan *et al*, 2010b). These benefits will only be fully realised if renewables projects embody limited imported materials and labour[138]. Onshore wind has been the major technology deployed so far in Scotland but it brings its own problem because of its intermittent nature, and therefore variable output, requiring a back-up to ensure supply meets demand.[139] Offshore wind and marine technologies have the potential to play an important role in Scotland given their abundance, although the peripheral location of the most promising resources provides new challenges to distribution and transmission.[140] It is estimated that Scotland has 25% of Europe's Tidal and Offshore wind power and 10% of its Wave power potential.

Carbon capture and storage (CCS) technology also has the potential in Scotland to stop emissions from coal or gas combustion being released into the atmosphere. CCS could be fitted to new or old power stations and allow for the use of coal and gas but without their significant CO2 emissions reaching the atmosphere. This is likely to be expensive to fund however as the technology has not yet been tested on a commercial scale, and these costs will likely be passed onto consumers through higher energy prices. The UK government announced a CCS demonstration competition as well as setting up an Office of Carbon Capture and Storage to coordinate the approach to CCS in the UK; this appears to be somewhat behind schedule. The EU has also passed a Directive on CCS and will use EU ETS proceeds

[138] There may also be benefits in terms of income flows to local communities, see Allan *et al* (2011)
[139] This back-up is most likely to come in the form of cheaper, dirtier sources such gas or coal, especially given that nuclear is not an option.
[140] This will therefore require significant upgrading of the electricity grid which was never designed with remote generating sources and renewables in mind.

to fund up to 12 CCS demonstrations. The development of CCS may take some time but Scotland has substantial capabilities to use its experience with the North Sea oil and gas industry, and the availability of extensive underground storage capacity, to help become a leader in CCS technology and use it to help achieve its environmental goals.

The Scottish Government has produced its own roadmap as to how Scotland can become Europe's leader in CCS technology (Scottish Government and Scottish Enterprise, 2010), the funding of which will be through EU and additional Scottish Government support. The export potential of CCS is particularly significant given that it could be adopted worldwide in countries which use coal and gas. In terms of the EU ETS it is not clear what will happen with CCS. Perhaps those installations fitted with CCS will be exempt from the EU ETS or they will otherwise be able to sell all their allowances. Overall, renewables should be preferred over CCS because although CCS helps to decarbonise the economy, in the long run and we would still be reliant upon finite fossil fuels and so it does not help address the energy supply. However, this does not diminish the value of CCS as an incredibly useful but ultimately short-to–medium term solution to reduce carbon emissions across the globe.

5 Policy instruments

Scotland is part of the United Kingdom and the European Union, and as such is subject to many of their climate change policies. At EU level Scotland is already included in the EU 20-20-20 targets for 2020 and policy instruments such as the EU ETS. At the UK level there are instruments such as the Climate Change Levy and the Carbon Reduction Commitment, renewables instruments such as Feed-in Tariffs (FiTs) and ROCs and there are institutions such as the Carbon Trust and the Energy Saving Trust. The Scottish Government must adhere to these given their limited devolved powers but must also use what it has at its disposal to achieve its own goals and the annual targets it sets.

The setting of emissions targets themselves may be seen as an instrument with which to achieve Scottish climate change goals. If targets are believed to be credible (i.e. in practice, if they are met year on year) then the mere setting of them may influence expectations sufficiently to alter behaviour, for example to induce investment in low carbon technologies. However, any such impact is likely to be short-lived if the Scottish Government consistently failed to meet its targets. It seems unlikely, in practice, that targets could be judged as being instruments, especially as there is no clear policy lever to make sure they are met. However, additional credibility of the targets may be brought about by advice on, and monitoring of, targets by an independent agency. The Climate Change (Scotland) Act allows for the possibility of a Scottish Committee on Climate Change to provide advice and progress towards annual targets. So far this possibility has not been utilised. However the Scottish Government commissioned a report from the Committee on Climate Change whose role it is to do this for the UK government (CCC, 2010a).[141]

The Scottish government has some other available options in terms of policy instruments. Firstly, the Scottish Government has been able to use its planning powers to help accelerate the achievement of its goals. An example of the use of planning permission is the acceptance of the Beauly to Denny power line, the creation of which will substantially enhance grid capabilities in Scotland. It will allow for easier transmission of electricity, in particular that generated by renewable sources located in peripheral areas to places of high energy consumption.

Secondly, the Scottish Government can make funding available for energy efficiency improvements and legislate to ensure efficiency standards in important emitting sectors such as transport, housing and agriculture. This may be through regulating efficiency standards e.g. of insulation, heating and lighting and also undertaking demand-side initiatives for transport, such as encouraging public transport, car sharing and lower speed limits.

[141] This report advises on: the highest achievable interim target for 2020; the annual targets from 2010-2020; a cumulative emissions budget; how to include aviation and shipping within budgets, and limiting the use of credits to meet Scottish targets. Their report was released in February 2010 and highlights the main differences between the Scottish and UK frameworks and how Scotland can attempt to meet its ambitious 42% reduction by 2020, most of which is detailed above.

Thirdly, there is the option of purchasing offset credits from the Kyoto mechanisms in order to meet emissions reduction targets. This may prove to be the cheapest option in the short-run if the price of these credits are low but, given the limit of 20% credit purchase in the Climate Change (Scotland) Act, they cannot rely heavily upon credits.

A fourth possible, but ultimately unlikely, action is for the Scottish Government to use its limited fiscal powers to inhibit growth in the economy in order to satisfy their climate change targets. This is highly unlikely given the potential consequences of such action but it should be noted that sustained low growth may make the achievement of targets possible i.e. targets may be met entirely fortuitously, rather than as a consequence of policy action.

In practice, the uptake of renewables will be achieved, not by climate change or renewables targets, but by direct funding and financial support over the time-scale necessary for investments. Extensive exploitation of renewable sources will require substantial funding by the Scottish and UK Governments in conjunction with the regulator Ofgem, given the integrated nature of the electricity market. How renewables are funded is a political decision but one which requires a balance between potentially "picking winners" on the one hand and effectively encouraging only the technology closest to market (a consequence of a "technology blind" approach). In the UK, renewables are substantially supported by the Renewable Obligation scheme which the Scottish government helps coordinate with other administrations and which Ofgem administers. This is a trading scheme that requires electricity suppliers to provide a certain amount of renewable power or face a penalty. The "banding" of ROCs was introduced by the UK Government to provide greater funding for newer technologies and by making them more cost competitive, to allow them to develop faster. The Scottish Government have gone even further and modified the ROC scheme so that wave and tidal energy receive greater funding in Scotland, than at UK level. At UK level wave and tidal power receive 2 ROCs per MW/hr but in Scotland wave now receives the equivalent of 5 ROCs per MW/hr and tidal receives 3 ROCs per MW/hr. This enhanced banding is particularly important for the marine energy sector, and may make tidal power comparable in costs to that of onshore wind (Allan *et al*, 2010c). However, it is not yet clear how this differential incentive is to be funded. Also, in April 2010 a UK-wide feed-in Tariff scheme (FiTs) was introduced to provide support for small-scale electricity generators.[142] The downside of this type of funding for renewables is that most of the high support costs are passed on to consumers in the form of higher energy prices. The Scottish Government also provides support through other schemes, funds and prizes to promote renewables, such as the Saltire Prize.

Overall, there are limited powers available to the Scottish Government to achieve its substantial climate change goal of effecting a 42% reduction in emissions by 2020. Why the Scottish Climate Change Act set an emissions reduction target which differs from the UK target, is not entirely obvious. It does not appear to be purely a supply-side decision as 42% is a very ambitious target that will not necessarily be easily met on current trends and maybe therefore require the purchase of offset credits. It may reflect a political stance in Scotland that is more sympathetic towards environmental objectives. One possibility is that, given the limited instruments available to the Scottish Government, in order to achieve their goals they are seeking to influence authorities, such as the UK Government, that do have more powerful instruments available. By setting the demanding 42% reduction target the Scottish Government may be seeking to influence UK policy.

One possible option would be for the Scottish Government to change the nature of the targets, or supplement them with additional targets focussed solely upon emissions generated within Scottish borders. Although this change goes against the principle of the EU ETS, in which the geographic location of emissions reductions is essentially irrelevant, it would provide a direct measure of emissions reductions within Scotland's borders. Clearly, in this case Scotland's new 80% renewables target may influence actual domestic CO2 emissions, while not contributing to the UK's emissions reduction target.

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[142] This scheme is stimulating considerable small-scale photovoltaic energy deployment in the southern regions of the UK

6 Conclusions

The aspiration of Scottish climate change policy, as expressed in their targets, is world leading. Currently the Scottish climate change framework is more ambitious than the UK counterpart. It includes international aviation and shipping, is independent of the EU framework and it sets annual targets. These make the Scottish framework tougher but less flexible than its UK equivalent. The Scottish targets will be more difficult to achieve but, if achieved, then this framework provide an appropriate contribution to Scotland's effort towards mitigating global climate change. These targets may also indirectly provide a credible incentive for substantial investment in renewable energy in Scotland, though direct funding for renewables is more appropriate in achieving this goal. If targets are missed regularly they will begin to lose credibility. Then measures such as banking, borrowing, using credits and adopting less frequent targets, should be taken to create more flexibility in meeting the targets. However, it is not clear that the Scottish Government actually has sufficient policy instruments to ensure achievement of its emissions reduction targets.

One major issue currently is that the Climate Change (Scotland) Act does not allow for the contribution of renewables towards the emissions reduction targets. Scotland's electricity sector is part of the EU ETS traded sector and as such emissions that "count" here are not Scotland's actual emissions from electricity generation but their share under the EU ETS. The Scottish Government has other energy policy goals of security of supply, price and economic growth. It has specific policies on achieving growth through renewables, with an 80% renewables target by 2020, and also phasing-out nuclear power, a decision at odds with emissions reductions given nuclear may be a cheap low-carbon option. Scotland has the potential to utilise and create new industries for low-carbon technologies. Large-scale deployment of technologies such as onshore and offshore wind, as well as a marine energy, could help promote a diverse and potentially lucrative renewable energy sector. However, given the current costs, these infant industries will require substantial support and funding from the Scottish and UK Governments through mechanisms such as ROCs. These must be set appropriately to induce the levels of investment necessary to meet the renewables targets. It is likely that costs from increasing renewable penetration will be passed onto consumers in the form of higher energy prices. Carbon capture and storage also has a role to play in helping to limit emissions from dirtier sources and there is also a potential for a growing worldwide industry too. CCS will require substantial development support to make it large-scale and regulation to enforce its adoption but ultimately it is not a long-term option.

Many determinants of emissions are beyond Scottish Government control e.g. energy prices, the EU ETS price and tax raising capabilities reserved to the UK Government. Therefore, should Scotland have its own climate change targets at all? The answer is probably not at present. Given that they do however, the Scottish Government must use the powers they have, such as planning permission, encouragement for renewables and efficiency benchmarking in the non-traded sectors, to maximum effect if they are to achieve the targets they have set. Perhaps it could set targets that are more obviously linked to the available instruments, specifically on the non-traded sector. Of course, the absence of instruments does not imply that the targets will not be achieved: they may be but as a consequence of forces outside the Scottish Government's control e.g. a prolonged period of low growth or a warm winter. Therefore it is important to know *why* and *how* targets are met. While there is a lack of instruments presently the Scottish Government may seek to exert influence on those that do have the necessary instruments or there may be a possible argument for granting more powers to the Scottish Government by extending the devolution agreement. Another option would be to change or supplement the accounting of emissions within the Scottish framework, to make it those emissions produced within Scotland's border than count towards the target and preferably make sure all GHGs are included within these targets.

This appendix is intended to provide a brief summary of the main issues that are specific to climate change policy in Scotland. I think it is far from clear that Scotland currently has the range of instruments that it would require to achieve its own targets. If this is the case then there are only a few solutions. One response may be for the Scottish Government to push for more instruments and this could be done by extending the powers afforded to them through devolution. Another response would be to either reduce the targets and thereby making them easier to meet, or to set different targets that the Scottish Government has more control over. What is quite clear is that it would be useful to extend evidence base relating to the feasibility, and likely costs, of any climate change policies. The CCC and DECC are considering some of these in detail. It would be useful, for example, to develop an energy-environment-economy model of the economy to simulate system-wide effects of changes in policy instruments through to the final goal outcomes.

Appendix C

Table C1: mapping of economic and environmental accounts

New 68 sector	Title 68 Aggregate sectors	123 sectors	UKIO 2004 123 sector name	93 sectors	Environmental accounting 93 sectors	SIC (2003) Agg sector
1	Agriculture	1	Agriculture, hunting and related service activities	1	Agriculture	AB
2	Forestry	2	Forestry, logging and related service activities	2	Forestry	AB
3	Fishing	3	Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing	3	Fishing	AB
4	Coal extraction	4	Mining of coal and lignite; extraction of peat	4	Mining of coal	C
5	Oil and gas extraction	5	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction	5	Extraction of petrol and gas	C
6	Metal ores extraction, Other mining and quarrying	6	Mining of metal ores	6	Mining of metal ores	C
		7	Other mining and quarrying	7	Other mining	C
7	Food and drink	8	Production, processing and preserving of meat and meat products	8	Food and beverages	D
		9	Processing and preserving of fish and fish products; fruit and vegetables			D
		10	Vegetable and animal oils and fats			D
		11	Dairy products			D
		12	Grain mill products, starches and starch			D

			products			
		13	Prepared animal feeds			D
		14	Bread, rusks and biscuits; manufacture of pastry goods and cakes			D
		15	Sugar			D
		16	Cocoa; chocolate and sugar confectionery			D
		17	Other food products			D
		18	Alcoholic beverages			D
		19	Production of mineral waters and soft drinks			D
8	Tobacco	20	Tobacco products	**9**	Tobacco products	D
9		21	Preparation and spinning of textile fibres	**10**		D
		22	Textile weaving			D
		23	Finishing of textiles			D
		24	Made-up textile articles, except apparel			D
		25	Carpets and rugs			D
		26	Other textiles			D
	Textiles	27	Knitted and crocheted fabrics and articles		Textiles	D
10	Wearing apparel	28	Wearing apparel; dressing and dying of fur	**11**	Clothing manufacture	D
11		29	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness	**12**		D
	Leather products	30	Footwear		Leather, luggage and footwear	D
12	Wood and wood products	31	Wood and wood products, except furniture	**13**	Timber	D
13		32	Pulp, paper and paperboard	**14**	Pulp and paper	D
		33	Articles of paper and paperboard	**15**		D
	Pulp and paper, printing and publishing	34	Publishing, printing and reproduction of recorded media		Publishing and printing	D

14	Coke ovens, refined petroleum & nuclear fuel	35	Coke, refined petroleum products and nuclear fuel	16	Coke oven products	D
				17	Refined petroleum products	D
				18	Processing of nuclear fuel	D
15	Industrial gases and dyes	36	Industrial gases, dyes and pigments	19	Industrial gases, dyes, pigments	D
16	Inorganic chemicals, Organic chemicals	37	Other inorganic basic chemicals	20	Other inorganic chemicals	D
		38	Other organic basic chemicals	21	Other organic basic chemicals	D
17	Fertilisers, Plastics & Synthetic resins etc, Pesticides	39	Fertilisers and nitrogen compounds	22	Fertilisers, nitrogen compounds	D
		40	Plastics and synthetic rubber in primary forms	23	Plastics and synthetic rubber	D
		41	Pesticides and other agro-chemical products	24	Pesticides, agro-chemicals	D
18	Paints, varnishes, printing ink etc	42	Paints, varnishes and similar coatings, printing ink and mastics	25	Paints, varnishes, ink etc	D
19	Pharmaceuticals	43	Pharmaceuticals, medicinal chemicals and botanical products	26	Pharmaceuticals	D
20	Soap and toilet preparations	44	Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	27	Soap and detergents	D
21	Other Chemical products, Man-made fibres	45	Other chemical products	28	Chemical products nes	D
		46	Man-made fibres	29	Man-made fibres	D
22	Rubber products	47	Rubber products	30	Rubber products	D
23	Plastic products	48	Plastic products	31	Plastic products	D
24	Glass and glass products	49	Glass and glass products	32	Glass and glass products	D
25	Ceramic goods	50	Ceramic goods	33	Ceramic goods	D
26	Structural clay products, Cement, lime and plaster	51	Bricks, tiles and construction products, baked in clay	34	Structural clay products	D
		52	Cement, lime and plaster	35	Cement, lime and plaster	D
27	Articles of concrete, stone etc	53	Articles of concrete, plaster and cement; cutting, shaping and finishing of stone; manufacture of other non-metallic products	36	Concrete, stone etc	D

28		54	Basic iron and steel and of ferro-alloys; manufacture of tubes and other first processing of iron and steel	**37**	Iron and steel	D
		55	Basic precious and non-ferrous metals	**38**	Non-ferrous metals excl. aluminium	D
		56		**39**	Aluminium	D
	Iron and steel, Non-ferrous metals, Metal castings		Casting of metals	**40**	Casting of metals	D
29		57	Structural metal products	**41**		D
		58	Tanks, reservoirs and containers of metal; manufacture of central heating radiators and boilers; manufacture of steam generators			D
		59	Forging, pressing, stamping and roll forming of metal; powder metallurgy; treatment and coating of metals			D
		60	Cutlery, tools and general hardware			D
	Metal products	61	Other fabricated metal products		Fabricated metal products	D
30		62	Machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines	**42**		D
		63	Other general purpose machinery			D
		64	Agricultural and forestry machinery			D
		65	Machine tools			D
		66	Other special purpose machinery			D
		67	Weapons and ammunition			D
	Machinery and equipment	68	Domestic appliances not elsewhere classified		Machinery and equipment	D
31	Office machinery and computers	69	Office machinery and computers	**43**	Office machinery, computers	D
32	Electrical machinery	70	Electric motors, generators and transformers; manufacture of electricity distribution and control apparatus	**44**	Electrical machinery and apparatus	D

		71	Insulated wire and cable			D
		72	Electrical equipment not elsewhere classified			D
33		73	Electronic valves and tubes and other electronic components	**45**		D
		74	Television and radio transmitters and line for telephony and line telegraphy			D
	Radio, television and communications	75	Television and radio receivers, sound or video recording or reproducing apparatus and associated goods		Radio, television and comms	D
34	Medical and precision instruments	76	Medical, precision and optical instruments, watches and clocks	**46**	Medical, precision and optical instruments, watches and clocks	D
35	Motor vehicles	77	Motor vehicles, trailers and semi-trailers	**47**	Motor vehicles and trailers	D
36		78	Building and repairing of ships and boats	**48**		D
		79	Other transport equipment			D
	Other transport equipment	80	Aircraft and spacecraft		Other transport equipment	D
37		81	Furniture	**49**	Manufacture of other products	D
		82	Jewellery and related articles; manufacture of musical instruments	**50**		D
		83	Sports goods, games and toys			D
	Other manufacturing and recycling	84	Miscellaneous manufacturing not elsewhere classified; recycling		Recyling	D
38		85		**51**	Electricity production - gas	E
				52	Electricity production - coal	E
				53	Electricity production - nuclear	E
				54	Electricity production - oil	E
	Electricity production and distribution		Production and distribution of electricity	**55**	Electricity production - other	E

39	Gas distribution	86	Gas; distribution of gaseous fuels through mains; steam and hot water supply	**56**	Gas distribution	E
40	Water supply	87	Collection, purification and distribution of water	**57**	Water supply	E
41	Construction	88	Construction	**58**	Construction	F
42	Motor vehicle distribution and repair, car fuel retail	89	Sale, maintenance and repair of motor vehicles, and motor cycles; retail sale of automotive fuel	**59**	Garages, car showrooms	GH
43	Wholesale distribution	90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	**60**	Wholesale trade except motor vehicles	GH
44	Retail distribution	91	Retail trade, except of motor vehicles and motor cycles; repair of personal and household goods	**61**	Retail & repair trade except motor	GH
45	Hotels, catering, pubs etc	92	Hotels and restaurants	**62**	Hotels and restaurants	GH
46	Railway transport	93	Transport via railways	**63**	Railways	I
47	Other land transport	94	Other land transport; transport via pipelines	**64**	Buses and coaches[1]	I
				65	Tubes and trams	I
				66	Taxis operation	I
				67	Freight transport by road	I
				68	Transport via pipeline	I
48	Water transport	95	Water transport	**69**	Water transport	I
49	Air transport	96	Air Transport	**70**	Air transport	I
50	Ancillary transport services	97	Supporting and auxiliary transport activities; activities of travel agencies	**71**	Supporting transport activities	I
51	Post and telecommunications	98	Post and courier activities	**72**	Post and telecomms	I
		99	Telecommunications			I
52	Banking and finance	100	Financial intermediation, except insurance and pension funding	**73**	Financial intermediation	JK

53	Insurance and pension funds	101	Insurance and pension funding, except compulsory social security	**74**	Insurance and pensions	JK
54	Auxiliary financial services	102	Activities auxiliary to financial intermediation	**75**	Auxiliary finance activities	JK
55		103	Real estate activities with own property; letting of own property, except dwellings	**76**		JK
		104	Letting of dwellings, including imputed rent			JK
	Real estate activities	105	Real estate activities on a fee or contract basis		Real estate activities	JK
56	Renting of machinery etc	106	Renting of machinery and equipment without operator and of personal and household goods	**77**	Renting of machinery	JK
57	Computer services	107	Computer and related activities	**78**	Computer and related activities	JK
58	Research and development	108	Research and development	**79**	Research and development	JK
59		109	Legal activities	**80**		JK
		110	Accounting, book-keeping and auditing activities; tax consultancy			JK
		111	Market research and public opinion polling; business and management consultancy activities; management activities			JK
		112	Architectural and engineering activities and related technical consultancy; technical testing and analysis			JK
		113	Advertising			JK
	Other business activities	114	Other business services		Other business activities	JK
60		115		**81**	Public administration, not defence	L
	Public admininstration and defence		Public administration and defence; compulsory social security	**82**	Public administration, defence	L
61	Education	116	Education	**83**	Education	MN
62	Health and social work	117	Human health and veterinary activities	**84**	Health and vet services,	MN

		118	Social work activities		social work	O
63		119		85	Sewage, treatment of liquid waste	O
			Sewage and refuse disposal, sanitation and similar activities	86	Solid waste	O
	Sewage and refuse services			87	Other sanitary services	O
64	Membership organisations	120	Activities of membership organisations not elsewhere classified	88	Activities of membership organisations	O
65	Recreational services	121	Recreational, cultural and sporting activities	89	Recreation and sporting activities	O
66	Other service activities	122	Other service activities	90	Other service activities	O
67	Private households with employed persons	123	Private households with employed persons	91	Private households	O
HH	Consumer expenditure - not travel			92	Consumer expenditure - not travel	Z
HH	Consumer expenditure - travel			93	Consumer expenditure - travel	Z

Appendix D

Table D1: UK Phase 1 sector classifications for UK facilities registered in EU ETS for "Combustion"

Heading	*Sub-heading*	*January NAP*	*May NAP*	*Number of installations*
Energy	Combustion installations	Generators	Power stations	123
			Coal mining	2
		Offshore	Offshore	110
			Other oil and gas	33
		Food and drink	Food and drink (non-CCA, FDF and CIA)	72
			Dairies	19
			Brewing	20
			Malting	4
			Spirits	6
			Rendering	10
			Poultry	2
		Chemicals	Chemicals – non-CCA	21
			Nuclear fuel – non-CCA	1
			Chemicals – CIA	81
			Nuclear fuel – CIA	1
		Non-ferrous	Aluminium	1
			Non-ferrous	1

		Others	Engineering and vehicles	17
			Rubber	4
			Aerospace	13
			Vehicle manufacture	14
			Cathode Ray Tubes	1
			Semiconductors	3
			Textiles	3
			Services	208
Ferrous metals	Pig iron or steel	Iron and steel	Iron and steel	4
Minerals	Glass	Glass	Glass – non-CCA	1
	Ceramics	Bricks/ceramics	Ceramics – BCC-N	1
			Other non-metallic	1
Other	Pulp	Pulp and paper	Pulp and paper – non-CCA	1
	Paper and board	Pulp and paper	Wood board – WPIF	3
Total number of installations				**781**

Source: Figure 1 – "Final UK Phase 1 sector classifications", ILEX Energy Consulting (2005)

Table D2: 25 sector input-output table with traded and non-traded sectors

	Purchases by industry group (basic prices) →	1	2	3	4	5	6	7	8	9	10	11	12	13
	↓ Sales by industry group ↓	Mining and quarrying	Food and Drink	Textiles; wearing apprrel; leather products	Wood; Pulp and paper; Printing and publishin g	Coke, refined petroleu m products and nuclear fuel	Gases and dyes; Chemical s	Glass and glass products	Ceramic goods	Clay, cement, lime and plaster	Articles of concrete, plaster and cement; stone	Iron and Steel; non-ferrous metals	manf of Motor vehicles and other of transport	Production and distribution of electricity
1	Mining and quarrying	853.2	25.1	3.3	19.3	8385.9	7.8	37.4	17.9	62.6	230.4	123.1	8.2	6079.5
2	Food and Drink	19.2	9481.6	75.8	109.8	32.4	11.7	2.6	6.8	1.5	6.8	11.6	55.7	29.0
3	Textiles; wearing apprrel; leather products	0.5	1.9	693.2	34.0	0.6	1.2	0.1	0.0	0.0	6.3	0.3	172.1	0.2
4	Wood; Pulp and paper; Printing and publishing	31.6	1361.9	200.6	10984.9	46.4	97.3	67.7	25.8	20.1	99.7	42.6	689.9	143.6
5	Coke, refined petroleum products and nuclear fuel	24.1	161.1	5.3	19.9	205.7	13.6	2.2	0.4	17.3	14.7	99.7	18.0	194.0
6	Gases and dyes; Chemicals	117.0	106.8	67.3	111.7	21.6	2089.7	29.3	6.4	2.4	74.6	97.7	25.6	48.0
7	Glass and glass products	6.7	244.8	0.0	46.4	0.0	0.1	134.2	0.0	0.1	23.4	0.0	357.4	0.1
8	Ceramic goods	3.6	0.2	0.1	0.2	0.0	0.1	2.3	40.1	12.7	0.9	71.5	0.8	0.2
9	Clay, cement, lime and plaster	216.9	2.1	0.1	1.0	0.0	0.1	0.8	0.1	4.8	329.0	8.8	3.5	2.2
10	Articles of concrete, plaster and cement; stone; manufacture of other non-metallic products	5.6	0.0	0.1	0.3	0.0	0.5	0.0	0.0	0.0	34.6	1.5	0.3	0.0
11	Iron and Steel; non-ferrous metals	16.2	11.2	6.6	4.7	15.6	21.4	24.9	0.5	1.1	55.6	725.6	1885.7	3.2
12	manf of Motor vehicles and other transport	131.1	16.4	11.0	22.1	0.7	5.1	0.5	0.5	0.6	2.1	3.5	3728.6	4.1
13	Production and distribution of electricity	302.7	579.5	109.6	588.1	126.3	363.9	107.9	34.5	96.2	88.4	534.1	425.7	9581.8
14	Agriculture, hunting and related service activities	2.7	6224.3	2.2	9.8	1.2	1.6	0.5	0.1	0.1	0.9	2.4	5.3	2.0
15	Forestry and fishing	1.0	280.8	1.1	121.1	0.3	0.5	0.4	0.1	0.1	0.5	0.7	2.2	0.7
16	Other Manufacturing	666.2	2130.9	375.9	1336.8	94.9	429.2	123.4	43.2	64.6	222.6	1985.9	9434.8	617.6
17	Gas and water supply; Construction	1217.4	679.3	121.1	458.6	271.1	316.1	95.7	36.6	77.9	100.0	298.7	517.1	2572.6
18	Wholesale retail trade; Repair of vehicles; personal goods; Hotels and restaurants	515.0	2941.4	1243.1	1879.2	806.7	827.9	231.1	93.5	80.0	524.8	2057.1	3424.9	759.9
19	Air Transport	113.0	28.5	11.7	137.9	14.7	24.4	1.1	5.1	5.1	17.4	56.5	126.0	1.4
20	Other Transport	1183.3	2242.5	434.1	1905.5	207.3	470.9	157.3	89.5	184.9	752.9	316.7	1014.7	219.8
21	Finance	2583.6	3003.0	826.3	1681.2	506.9	1066.5	154.2	102.1	83.5	483.4	1067.3	3243.6	1087.3
22	Real Estate, renting and business activities	1552.4	2975.1	475.2	2027.3	222.1	156.3	93.4	42.6	26.9	185.9	185.3	1880.7	440.1
23	Public admin and defence; compulsory social security	22.5	43.7	30.6	25.4	10.8	10.5	3.0	1.3	0.4	0.6	22.2	56.0	15.4
24	Education; Health and social work	34.1	121.3	40.7	68.6	19.2	36.7	5.4	3.8	0.9	7.8	16.1	150.3	64.9
25	Other service; Private households with employed persons	90.6	334.4	60.2	1294.3	23.0	58.9	12.8	11.1	2.4	32.4	55.3	167.5	80.9
Total domestic consumption at basic prices		9710.1	32997.7	4795.0	22887.7	11013.5	6012.1	1288.4	562.2	746.3	3295.8	7784.3	27394.8	21948.6
	Imports from Rest of World	2343.1	9785.8	2336.9	7188.5	5217.1	3311.9	416.7	233.5	179.2	827.4	4096.4	16171.2	1593.9
Total intermediate consumption at basic prices		12053.2	42783.5	7131.9	30076.3	16230.6	9324.0	1705.1	795.7	925.4	4123.2	11880.7	43566.1	23542.5
	Net taxes on products and production	118.6	285.1	87.4	403.7	55.5	58.5	30.2	15.5	23.4	70.3	91.4	203.1	706.4
	Compensation of employees	2915.6	14020.6	3257.6	15405.1	2283.6	2004.1	964.1	653.5	505.9	1800.4	2497.1	13216.0	2688.1
	Gross operating surplus	17168.2	5074.7	325.5	6595.8	-249.1	253.5	241.2	84.1	301.8	551.4	-122.4	795.2	6259.7
Gross output/expenditure at basic prices		32255.6	62163.9	10802.4	52480.8	18320.6	11639.9	2940.6	1548.9	1756.5	6545.4	14346.7	57780.4	33196.7

	Purchases by industry group (basic prices) →	14	15	16	17	18	19	20	21	22	23	24	25	
	↓ Sales by industry group ↓	Agriculture, hunting and related service activities	Forestry and fishing	Other Manufacturing	Gas and water supply; Construction	Wholesale retail trade; Repair of vehicles; personal goods; Hotels and restaurants	Air Transport	Other Transport	Finance	Real Estate, renting and business activities	Public admin and defence; compulsory social security	Education; Health and social work	Other service; Private households with employed persons	**Total Intermediate Demand**
1	Mining and quarrying	2.7	0.3	220.2	2232.4	192.1	1.6	75.2	39.6	100.3	18.9	24.2	35.8	18797.1
2	Food and Drink	1827.5	49.1	242.3	50.7	14966.9	58.4	439.0	281.7	566.1	170.7	1996.5	815.5	31308.9
3	Textiles; wearing apprrel; leather products	92.8	3.0	326.7	124.0	519.3	1.9	17.6	25.1	37.1	78.2	212.2	67.9	2416.6
4	Wood; Pulp and paper; Printing and publishing	267.6	32.5	3658.1	3390.9	2581.3	32.6	928.8	2831.8	2828.3	2289.1	3108.4	1106.0	36867.6
5	Coke, refined petroleum products and nuclear fuel	226.0	91.9	92.8	447.6	1597.7	900.2	1690.4	325.2	347.0	778.5	560.2	155.6	7988.9
6	Gases and dyes; Chemicals	27.2	1.6	1231.4	104.3	106.5	2.3	34.6	41.8	116.8	72.9	247.8	126.9	4912.3
7	Glass and glass products	10.0	0.1	365.7	432.9	272.3	5.6	32.0	0.7	4.8	71.3	63.3	25.2	2097.2
8	Ceramic goods	0.0	0.0	78.9	238.3	102.7	1.0	8.3	0.4	2.8	47.0	35.2	11.0	658.4
9	Clay, cement, lime and plaster	24.8	0.0	4.7	777.4	46.3	0.0	21.9	0.5	6.0	55.1	84.7	55.1	1645.9
10	Articles of concrete, plaster and cement; stone; manufacture of other non-metallic products	28.8	0.1	5.2	4979.2	298.6	0.0	41.6	1.0	18.2	90.2	113.8	134.7	5754.5
11	Iron and Steel; non-ferrous metals	7.8	1.0	4363.8	223.2	102.4	20.8	68.3	4.8	25.0	8.3	2.8	6.8	7607.4
12	manf of Motor vehicles and other transport	25.9	50.3	181.8	40.0	2332.1	104.3	612.5	176.0	236.7	1054.4	285.7	76.1	9101.9
13	Production and distribution of electricity	185.0	48.2	2029.3	2310.2	1860.6	55.2	731.7	502.2	916.2	639.9	1002.1	354.2	23573.5
14	Agriculture, hunting and related service activities	813.9	0.2	258.3	108.5	1500.1	4.0	41.2	50.7	45.2	31.6	107.3	22.5	9236.5
15	Forestry and fishing	1.7	343.8	22.1	136.9	256.5	0.2	17.1	4.4	7.9	8.7	9.9	3.5	1222.1
16	Other Manufacturing	926.3	39.5	23868.3	9794.3	3452.2	51.7	2553.4	513.0	1492.3	5967.6	6889.7	1603.9	74678.3
17	Gas and water supply; Construction	328.4	93.6	1500.4	53225.4	2280.8	30.9	2105.2	2465.9	9757.4	4243.5	1466.7	686.5	84946.9
18	Wholesale retail trade; Repair of vehicles; personal goods; Hotels and restaurants	2403.6	65.8	12972.1	4229.3	9188.2	354.5	4127.4	4033.4	4025.2	5703.5	8347.5	1552.3	72387.6
19	Air Transport	5.3	0.5	161.6	53.0	855.0	481.8	1142.6	1434.5	969.8	136.0	108.9	277.9	6169.8
20	Other Transport	330.2	100.4	4962.7	1474.7	31809.8	1030.9	28109.3	13471.3	8653.6	3965.1	4970.5	2305.7	110363.7
21	Finance	738.8	58.5	12074.4	2229.3	12795.1	665.8	4619.4	24901.6	10339.8	10683.7	2168.1	1331.5	98495.1
22	Real Estate, renting and business activities	1057.3	38.2	6793.3	17649.3	43863.3	1469.0	17833.2	24058.1	62168.6	9739.2	12041.3	10778.1	217752.3
23	Public admin and defence; compulsory social security	8.5	5.8	324.9	292.8	210.2	53.1	806.3	55.3	4284.4	225.9	55.5	67.5	6632.5
24	Education; Health and social work	166.2	3.0	630.2	220.3	1124.2	89.5	1022.4	1760.4	3207.0	3201.1	27286.4	941.3	40221.8
25	Other service; Private households with employed persons	152.3	39.7	661.2	366.5	2608.4	161.9	1762.6	1320.3	3692.2	2030.6	3195.5	13131.4	31346.6
Total domestic consumption at basic prices		9658.8	1067.3	77030.5	105131.3	134922.6	5577.0	68842.1	78299.9	113849.0	51311.0	74384.4	35673.0	906183.5
	Imports from Rest of World	2222.1	92.3	33748.1	11136.2	16552.8	3038.8	13082.5	6582.3	12746.5	11828.5	13552.1	8528.3	186812.2
Total intermediate consumption at basic prices		11880.9	1159.6	110778.6	116267.5	151475.4	8615.9	81924.7	84882.2	126595.4	63139.5	87936.5	44201.3	1092995.6
	Net taxes on products and production	-427.4	12.7	1117.0	1074.2	7822.7	86.5	1586.0	1372.3	1631.5	0.0	158.4	915.6	17498.6
	Compensation of employees	3144.0	272.8	49158.4	33903.5	105120.3	3241.0	51408.9	38237.0	106705.2	47518.4	119967.4	34784.9	655673.3
	Gross operating surplus	6536.9	432.4	10919.4	36295.1	44794.5	2713.4	19150.7	39412.5	147574.1	546.3	17345.0	19923.0	382922.9
Gross output/expenditure at basic prices		21134.5	1877.5	171973.4	187540.2	309213.0	14656.8	154070.4	163903.9	382506.3	111204.1	225407.4	99824.7	2149090.5

	Purchases by industry group (basic prices) →	**Final consumption expenditure**					**Gross capital formation**				**Exports**				
	↓ Sales by industry group ↓	Households	NPISHs	Central Government	Local Government	**Total**	GFCF	Valuables	Change in Inventories	**Total**	EU	Non-EU	**Total**	**Total Final Demand**	**Total Demand for Products**
1	Mining and quarrying	140.4	0.0	0.0	0.0	140.4	172.1	-0.7	90.0	261.4	8268.1	4788.8	13056.8	13458.6	32255.7
2	Food and Drink	24917.7	0.0	0.0	0.0	24917.7	1.0	0.0	158.7	159.7	4113.4	1664.2	5777.6	30855.0	62163.9
3	Textiles; wearing apprrel; leather products	3282.8	0.0	0.0	0.0	3282.8	529.6	0.0	49.4	579.0	2562.6	1961.4	4524.1	8385.8	10802.4
4	Wood; Pulp and paper; Printing and publishing	8855.8	0.0	0.0	0.0	8855.8	1022.1	-4.9	29.2	1046.4	3242.3	2468.7	5711.0	15613.2	52480.8
5	Coke, refined petroleum products and nuclear fuel	2237.5	4.8	0.0	0.0	2242.3	0.2	0.0	0.0	0.2	4905.9	3183.3	8089.2	10331.7	18320.6
6	Gases and dyes; Chemicals	131.7	10.1	0.0	0.0	141.8	5.9	0.0	0.0	5.9	4663.3	1916.7	6580.0	6727.7	11639.9
7	Glass and glass products	194.6	0.0	0.0	0.0	194.6	7.4	0.0	7.9	15.3	441.0	192.6	633.6	843.4	2940.6
8	Ceramic goods	406.0	0.0	0.0	0.0	406.0	23.0	0.0	0.0	23.0	240.0	221.6	461.6	890.6	1548.9
9	Clay, cement, lime and plaster	30.7	0.0	0.0	0.0	30.7	23.7	0.0	5.3	29.0	32.1	18.9	50.9	110.6	1756.5
10	Articles of concrete, plaster and cement; stone; manufacture of other non-metallic products	146.6	0.0	0.0	0.0	146.6	67.5	0.0	26.2	93.7	394.2	156.4	550.5	790.9	6545.4
11	Iron and Steel; non-ferrous metals	20.5	0.0	0.0	0.0	20.5	2.8	0.0	32.5	35.4	3953.4	2730.2	6683.5	6739.4	14346.7
12	manf of Motor vehicles and other transport	15166.5	3.4	0.0	0.0	15169.8	1927.4	0.0	432.6	2360.0	17385.7	13762.8	31148.6	48678.4	57780.4
13	Production and distribution of electricity	9423.8	0.0	0.0	0.0	9423.8	0.4	0.0	0.0	0.4	166.1	32.8	198.9	9623.2	33196.7
14	Agriculture, hunting and related service activities	9960.2	4.1	4.6	5.6	9974.5	752.6	0.0	0.0	752.6	767.1	403.8	1170.9	11898.0	21134.5
15	Forestry and fishing	200.5	1.1	0.1	0.1	201.7	2.0	0.0	3.7	5.8	357.2	90.7	447.9	655.4	1877.5
16	Other Manufacturing	17014.2	22.7	0.0	0.0	17036.9	12651.5	-30.9	343.9	12964.6	37797.4	29496.2	67293.6	97295.1	171973.4
17	Gas and water supply; Construction	12933.9	0.0	0.0	0.0	12933.9	87914.1	-0.3	1473.9	89387.7	49.8	221.9	271.6	102593.3	187540.1
18	Wholesale retail trade; Repair of vehicles; personal goods; Hotels and restaurants	208549.2	6.2	3.2	5.1	208563.6	7889.1	-305.9	13.1	7596.2	10706.3	9959.2	20665.5	236825.3	309212.9
19	Air Transport	5168.2	0.0	0.0	0.0	5168.2	3.2	-1.8	0.0	1.5	1439.6	1877.7	3317.3	8487.0	14656.8
20	Other Transport	29195.6	2.7	0.1	0.1	29198.5	1221.8	-122.1	9.7	1109.4	6108.6	7290.2	13398.7	43706.6	154070.4
21	Finance	38218.0	182.8	0.0	0.0	38400.8	321.7	-2.4	3.3	322.6	9982.1	16703.3	26685.4	65408.8	163903.9
22	Real Estate, renting and business activities	100764.9	857.9	10.6	129.2	101762.6	24357.9	-2.1	226.5	24582.3	15885.8	22523.1	38409.0	164753.9	382506.3
23	Public admin and defence; compulsory social security	2463.2	0.0	69605.5	30114.6	102183.2	1269.4	0.0	1.4	1270.8	433.7	683.9	1117.6	104571.6	111204.1
24	Education; Health and social work	23470.1	21572.3	78872.7	59267.2	183182.3	52.4	0.0	12.3	64.7	802.9	1135.7	1938.6	185185.5	225407.4
25	Other service; Private households with employed persons	40598.0	6178.4	3338.7	8558.8	58673.9	2646.0	-4.8	44.5	2685.6	2298.1	4820.5	7118.6	68478.1	99824.7
Total domestic consumption at basic prices		553490.5	28846.5	151835.4	98080.7	832253.1	142864.8	-476.0	2964.1	145353.0	136996.7	128304.3	265301.0	1242907.0	2149090.5
	Imports from Rest of World	93772.1	0.0	0.0	0.0	93772.1	39510.2	646.6	1947.2	42104.0	5969.8	5463.7	11433.4	147309.5	334121.7
Total intermediate consumption at basic prices		647262.6	28846.5	151835.4	98080.7	926025.2	182374.9	170.7	4911.3	187456.9	142966.4	133768.0	276734.4	1390216.5	2483212.1
	Net taxes on products and production	82463.4	0.0	0.0	0.0	82463.4	11234.3	-212.8	-88.6	10932.9	11271.0	9445.9	20716.9	114113.2	131611.9
	Compensation of employees	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	655673.3
	Gross operating surplus	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	382922.9
Gross output/expenditure at basic prices		729726.0	28846.5	151835.4	98080.7	1008488.6	193609.2	-42.1	4822.7	198389.8	154237.5	143213.8	297451.3	1504329.7	3653420.2

Appendix E

Employment for generating technologies

In order to create estimates for compensation of employees for each generating technology in the modified IO table some assumptions had to be made using available data.

The Annual Business Inquiry (ABI) by ONS (2010c) showed that for 2004 there were roughly 67,000 people employed in all electricity (SIC 40.1) with total employment costs of around £2,508 million. This compared with the original UKIO table for 2004 which gave total compensation of employees in the production, distribution and transmission of electricity as £2688.1 million.

Table E1: Employment figures for electricity sector (2004)

Year: 2004	SIC	Total employment - average during the year (thousands)	Total employment costs £million
Production of electricity	40.11	20	717
Transmission of electricity	40.12	13	580
Distribution and trade in electricity	40.13	34	1,211
Production and distribution of electricity	40.1	67	2,508

The ABI then goes further to split these figures out into production (40.11), transmission (40.12) and distribution and trade (40.13). It shows that the average number of employees in only the production of electricity is 20,000 and that the total cost of employment in electricity production is £717 million. This is almost 30% of the total employment costs for the electricity sector. If we assume that the ABI share of employment is correct then we can take 30% of compensation of employees for electricity in the UKIO table to give total wages for generation of £826.42 million. It is also possible to use these figures to calculate an average salary of those employed in production of electricity in 2004 as being £35,850.

Average salary in electricity production = £717,000,000 / 20,000 = £35,850

One method of disaggregating employment costs was to simply apportion each technology their share of the 30% based upon their own share of total generation. This method appeared to overestimate the overall number of jobs in the electricity generation and paid no attention to difference in labour and capital intensities of the various technologies.

Instead a different approach is applied. I used calculations from data used by Allan *et al* (2007a) on the number of jobs per MWh for each technology. These were originally calculated using industry data on individual plants. For instance, nuclear generation at the Hunterston power station in Scotland had 496 full-time employees which generated 8322 MWh in 2000 giving it a job per GWh generation coefficient of 0.06. This coefficient was calculated for each technology and was then multiplied by the total generation of that technology in the UK in 2004 to give the number of jobs in each sector. For nuclear, which generated 79,999 MWh in 2004, this was 4768 jobs. The number of jobs for each technology was then multiplied by the average wage of £35,850 to get a total "compensation of employees" for each technology. When summed together these wages added to £652 million for total generation. These were then scaled up for each technology in order to get a total compensation of wages figure for generation of £826.42 million.

Table E2: Cost breakdown of disaggregated electricity sectors

	Electricity Supply	Generation - Nuclear	Generation - Coal	Generation - Gas + Oil	Generation - Hydro	Generation - Biomass	Generation - Wind	Generation - Wind Offshore	Generation - Other	Generation - Marine/solar
Intermediate purchases	69.34%	28.90%	49.27%	77.36%	27.57%	52.63%	61.07%	60.36%	31.52%	60.84%
Imports	4.84%	4.80%	4.87%	4.80%	0.00%	0.00%	4.80%	4.76%	4.80%	4.80%
Taxes	3.44%	2.13%	2.13%	2.13%	2.13%	2.13%	2.13%	2.11%	2.13%	2.13%
Employees	7.48%	7.35%	9.37%	7.72%	38.14%	54.23%	23.12%	32.86%	54.23%	38.14%
GOS	14.90%	56.82%	34.37%	7.99%	32.17%	-8.99%	8.88%	-0.09%	7.32%	-5.91%

Table E3: Disaggregated electricity sector matrix in IO 29 sector table

	Purchases by industry group (basic prices) → ↓ Sales by industry group ↓	13 Electricity Supply	14 Generation - Nuclear	15 Generation - Coal	16 Generation - Gas + Oil	17 Generation - Hydro	18 Generation - Biomass	19 Generation - Wind	20 Generation - Wind Offshore	21 Generation - Other	22 Generation - Marine/solar
1	Mining and quarrying	3968.4	0.0	788.3	1322.8	0.0	0.0	0.0	0.0	0.0	0.0
2	Food and Drink	21.8	1.5	2.4	3.0	0.1	0.1	0.0	0.0	0.1	0.0
3	Textiles; wearing apprrel; leather products	0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	Wood; Pulp and paper; Printing and publishing	107.7	17.3	12.1	4.8	0.4	0.7	0.2	0.0	0.3	0.0
5	Coke, refined petroleum products and nuclear fuel	0.0	194.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Gases and dyes; Chemicals	36.0	5.5	4.0	2.0	0.1	0.2	0.1	0.0	0.1	0.0
7	Glass and glass products	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	Ceramic goods	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	Clay, cement, lime and plaster	1.6	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
10	Articles of concrete, plaster and cement; cutting, shaping and finishing of stone; manufacture of other non-metallic products	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	Iron and Steel; non-ferrous metals	2.4	0.2	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
12	manf of Motor vehicles and other transport	3.1	0.2	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0
13	Electricity Supply	1282.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	Generation - Nuclear	1697.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	Generation - Coal	2795.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	Generation -Gas + Oil	3430.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	Generation - Hydro	102.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	Generation - Biomass	162.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	Generation - Wind	36.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	Generation - Wind Offshore	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	Generation - Other	65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	Generation - Marine/solar	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	Agriculture, forestry and fishing	2.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	Other Manufacturing	463.2	51.6	57.0	38.8	1.9	3.0	0.7	0.1	1.2	0.1
25	Gas and water supply; Construction	1074.0	40.8	227.1	1135.6	13.1	51.1	13.9	1.6	13.6	1.9
26	Wholesale retail trade; Repair of vehicles; personal and household goods; Hotels and restaurants	570.0	58.8	84.0	38.5	2.4	3.7	0.8	0.1	1.5	0.1
27	Air Transport	1.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
28	Other Transport	164.9	21.2	18.5	12.7	0.7	1.1	0.2	0.0	0.4	0.0
29	Services	1266.5	126.3	182.2	94.5	5.2	8.2	1.9	0.2	3.3	0.3
Total domestic consumption at basic prices		17264.7	517.7	1377.3	2654.0	24.0	68.3	17.9	2.0	20.5	2.4
	Imports from Rest of World	1206.2	81.5	136.2	164.7	0.0	0.0	1.8	0.2	3.1	0.2
Total intermediate consumption at basic prices		18470.9	599.1	1513.6	2818.7	24.0	68.3	19.6	2.2	23.6	2.7
	Net taxes on products and production	529.8	36.1	59.5	73.0	2.2	3.5	0.8	0.1	1.4	0.1
	Compensation of employees	1881.7	211.3	221.9	224.3	33.2	74.5	8.3	1.4	29.9	1.6
	Gross operating surplus	4015.2	850.5	1000.8	314.5	43.4	15.9	8.1	0.5	10.1	0.6
Gross output/expenditure at basic prices		24897.6	1697.0	2795.7	3430.5	102.8	162.1	36.9	4.2	65.0	5.0

Appendix F

Table 5.3: Summary of CGE carbon tax papers

Author/Year	Region	Type of policy	Recycling	Double Dividend	Comments
Agostini *et al* (1992)	EU	Low, medium and high carbon tax related to fossil fuels	N/A	N/A as no recycling	Largest emissions reduction in electricity sector
Andre et al (2005)	Andalucia	Revenue neutral CO2 tax of six varying levels	Recycled through income tax or payroll tax reductions	Achieved only with Payroll tax recycling	Authors believe payroll tax is highly distorting
Bor and Huang (2010)	Taiwan	Energy taxes on fossil fuels	Six scenarios including no recycling, individual and business income taxes, and Gov expenditure	DD of increased GDP when recycled through individual and business income tax	Individual recycling achieves greater GDP impact than any other
Fraser and Waschik (2010)	Australia and UK	Carbon tax. Endogenous labour supply. Incorporates fixed-factors for polluting goods	Reductions in consumption or income tax	DD in Australia for consumption recycle. None in UK	UK energy sector smaller than AUS so less revenue
Manresa and Sancho (2005)	Spain	Revenue neutral "ecotax" and model a rigid and flexible labour market	Simulate 1) no recycling, and 2) labour tax	Unemployment DD achieved with recycling	Flexibility in labour market helps possibility of double dividend.

Palatnik and Shechter (2008)	Israel	Four carbon tax levels. Two different labour market scenarios; Fixed and endogenous	1) All pre-existing taxes reduced equally 2) Reduce income tax	Increased employment under endogenous labour supply	Substitution between labour and capital imported
Sancho (2010)	Spain	Two scenarios. 10% energy tax and 15% increase Petrol tax. Then double both these	Reduced payroll tax	DD of improve welfare and employment	DD only achieved where labour and capital can substitute
Scrimgeour et al (2005)	New Zealand	Effects of carbon, energy and petroleum taxes on emissions and economy	N/A	N/A as no recycling	Carbon tax most effective at reducing emissions but it also reduces GDP the most
Takeda (2007)	Japan	Carbon taxes to achieve four different emissions targets.	Recycled by labour income tax, capital income tax, consumption tax, capital tax, and labour tax	Capital tax recycling achieves improved lifetime utility	Compare recycling methods against lump-sum return of revenues
Welsch (1996)	EC	Carbon (and energy?) tax simulating EC proposals. Two different wage elasticities with respect to unemployment	Through wage subsidy	Yes. Higher with the lower wage elasticity	Greater emissions reductions with the higher wage elastcity
Wissema and Dellink (2007)	Ireland	Reduction in CO2 emissions by 25.8%	N/A	N/A	Achieved by carbon tax of €10-15 per tonne of CO2
Zhang (2002)	China	Reduction in emissions by 20% and 30% against a baseline scenario	3 cases: No recycling; Reducing indirect taxes by 5% ; or by 10%	Achieved when 20% emissions reduction and recycling through 10% tax reduction	Recycling increases consumption and international competitiveness against no recycling case

Appendix G

CO_2 emissions per £1m input or ouput (in Tonnes of CO_2)	coal		Gas		oil		output
	Domestic	Import	Domestic	Import	Domestic	Import	
Coal Mining and quarrying	12,964	1,921	0	0	9,419	2,602	0
Gas Mining and quarrying	0	0	4,510	144,087,839	11,692	30,387	183
Coke ovens, refined petroleum and nuclear fuel	3,414,709,211	157,906	225	19,559,178	29,669	205,496	0
Other traded e.g. Food and drink	122,277	11,374	14,196	145,056,540	18,340	135,590	8
Pulp and Paper	144,128	8,043	18,030	34,758,443	40,125	11,669	9
Glass and Ceramics	0	0	16,004	18,717,512	44,915	3,896	176
Clay, cement, lime and plaster	3,189	1,655	11,394	7,877,449	33,958	19,734	6,260
Iron and Steel; non-ferrous metals	45,491,881	78,275	5,190	14,460,379	83,090	319,879	266
Generation - Coal	57,286	1,666,769	0	0	0	833	0
Generation -Gas + Oil	0	0	20,176	511,455,351	0	9,559	154
Electricity distribution and supply	0	0	0	0	0	859	318
Generation - Nuclear	0	0	0	0	132	859	8
Generation - Hydro	0	0	0	0	0	0	0
Generation - Biomass	0	0	0	0	0	0	0
Generation - Wind	0	0	0	0	0	0	0
Generation - Wind Offshore	0	0	0	0	0	0	0
Generation - Other	0	0	0	0	0	0	0
Generation - Marine/solar	0	0	0	0	0	0	0
Agriculture; Forestry and fishing	5,708,029	305	9,151	3,979,157	8,934	95,640	80
Water	0	0	107,035	15,649,277	1,429,968	39,802	0
Construction	0	0	5,016	4,770,303	14,001	176,813	16
Other Manufacturing and wholesale retail trade	788,983	21,457	11,360	158,945,179	5,814	330,902	15
Air Transport	0	0	2,621	353,428	37,047	749,325	0
Other Transport	0	0	3,363	5,704,612	27,895	1,004,010	0
Services	81,729	7,652	10,781	135,829,219	2,610	190,360	4
Households	417,168	58,422	64,969,354	10,140	45,815,545	33,010	38

Appendix H

Table H1: elasticity of substitution in UKENVI model for different assumptions

Elasticity of substitutions`	Default	elast (1)	Elast(2)
X=INT+VA	0.3	0.3	0.3
ENERGY AND NON ENERGY	0.3	0.3	0.3
ELECTRITY AND NON ELECTRICITY+	2	**0.3**	2
COAL AND NON COAL	2	2	2
TRANSMISSION AND GENERATION	0.3	0.3	0.3
INTERMETTED AND NONINTERMETTED	5	5	**10**
BETWEEN ZNIN	5	5	**10**
WIND AND MARINE	5	5	**10**
IN AND OFF SHORE WIND	5	5	**10**
BETEEN NON ENERGY	0.3	0.3	0.3
LOW AND HIGH CARBON	5	5	**10**
OIL AND GAS	2	2	2