THE ECONOMIC EFFECTS

OF

CARBON TAXES

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Edited by John Fitz Gerald and Daniel McCoy

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PREFACE

International concern about the possibility of global warming and the potential consequences for the world has grown rapidly over the last ten years. It is now a major concern of policy makers who will meet at the special United Nations Conference on the Environment and Development (UNCED) in Brazil in June 1992, officially known as the "Earth Summit". While scientific evidence concerning the magnitude and timing of the problem remains weak, the major potential factor driving this warming process appears to be the growth in man-made emissions of certain gases. One of the most important of these gases is carbon dioxide, CO_2. Last autumn, as part of its preparations for this United Nations conference, the EC Commission proposed a new set of policies aimed at reducing man made production of carbon dioxide. While these policy measures have not been agreed by member governments they remain on the agenda of the EC.

This Policy Research Series paper documents the proceedings of a conference held at the ESRI in November 1991 entitled *Controlling Carbon Dioxide Emissions: The Economic Implications for Ireland.* The conference focussed on the likely economic implications of the European Commission's draft proposals on a Community strategy to limit carbon dioxide emissions and to improve energy efficiency.

The Commission's proposals grew out of the decisions taken by the EC Council of Ministers in June 1990, known as the "Dublin Declaration". This declaration committed the Community to using its moral, economic and political authority to encourage more intensive international efforts to solve global environmental problems. Emphasis is placed on achieving international cooperation on the issue of climate change. The introduction of the proposed measures would be expected to give the EC a leading role in the negotiations on an international convention on climate change. It is hoped that this convention will be completed for signature at the "Earth Summit".

The international concern about climate change and the perceived need for affirmative action stems from an influential scientific report on global warming, published in 1990 by the UN sponsored Intergovernmental Panel on Climate Change (IPCC). The IPCC findings suggest that in a business-as-usual scenario average global temperature would rise about 0.3°C each decade during the next century. This global warming could be expected to induce climatic changes and to lead to rising sea levels. The IPCC attributed these changes to the rapid growth in the emissions of man-made greenhouse gases (GHGs) over the last few decades, see Box A for a summary description of the process of global warming.

BOX A

WHAT IS THE "PROBLEM"?

Few, if any, issues have captured the attention of world-wide media and policy-makers over the last decade as the international concern for the natural environment. Much of this attention has focused on the prospect of global warming induced by human activity leading to rising sea levels and climatic changes. The cause of this warming revolves around the "Greenhouse Effect". This effect was first postulated in the early 19th century but it has only been catapulted to prominence in the 1980s, in many cases by the presentation of catastrophic scenarios for the earth's climate. What is the "Greenhouse Effect"?

All bodies in space emit radiation, including the earth and its atmosphere. The earth receives short wave heat rays from the sun which heat up its surface. The earth then re-emits long wave heat rays. Certain gases naturally present in the earth's atmosphere allow short wave heat to pass through but trap a considerable amount of the long wave radiation from the earth. The effect is similar to that of a greenhouse in that it allows incoming heat but traps outgoing heat. The impact of these gases is to make the earth's surface warmer than it would be in their absence. The earth's surface currently has an average temperature of 15°C; without the "Greenhouse Effect" it would be -18°C.

The concentration of the so-called "Greenhouse Gases" (GHGs) in the atmosphere has increased rapidly in recent decades as a result of population growth and industrialisation. The predicted consequence of this increase in man-made GHGs is an increase in global temperatures causing rising sea levels as the polar ice-caps melt. Changes in the sea levels will alter the climate in various regions of the globe. The major man-made GHGs include Carbon Dioxide (CO_2), Methane (CH_4), chlorofluorocarbons (CFCs), nitrous oxide (N_2O) and tropospheric ozone (O_3). The relative importance of each of these gases to the "Greenhouse Effect" is shown in Table A. Energy use is the single most important contributor of man-made GHGs, particularly the burning of fossil fuels like coal and oil.

As shown in Table A, carbon dioxide (CO_2) is identified as the major GHG. The main source of man-made CO_2 emissions is from economic activities such as deforestation and the burning of fossil fuels for energy uses. The findings of the IPCC seem to have gained a wide acceptance by policy makers. An international conference on global warming held in Toronto in 1988 agreed that worldwide CO_2

Table A: *Sources of the Greenhouse Effect*

Contribution of Greenhouse Gases by Activity (%)						
	CO_2	CFC	CH_4	O_3	N_2O	*Total*
Energy	35		4	6	4	49
Deforestation	10		4			14
Agriculture	3		8		2	13
Industry	2	20		2		24
% Warming by Gas	50	20	16	8	6	100

Source : OECD (1991), The State of the Environment.

emissions needed to be controlled. The Toronto Agreement calls on industrialised countries to reduce their CO_2 emissions by 20 per cent of their 1988 levels by the year 2000.

Unlike other pollutants it is not possible to "clean up" emissions of CO_2. The carbon dioxide emissions from the combustion of fossil fuels can only be reduced by:

(i) changes in technology towards less use of energy,
(ii) increases in the efficiency of energy use,
(iii) changing the mix of fuels,
(iv) any combination of the above.

There is still significant scientific uncertainty about whether and how rapidly global warming will occur and, if it does, how much of it will be attributable to the emission of man-made GHGs. Given the scientific uncertainty the EC Commission are advocating a precautionary approach: it is better to take limited action now at minimal cost lest the worst predictions prove justified. Their strategy is to stabilise the Community's emissions of carbon dioxide by the year 2000 at their 1990 levels. The emphasis is on reducing the energy requirements of economic growth in order to reduce carbon emissions.

The proposals under discussion are contained in a draft communication of the 30th September 1991 by the European Commission to the Council of Ministers entitled *A Community Strategy to limit carbon dioxide emissions and to improve energy efficiency.*

Measures are proposed in the field of regulation and in Research & Development (R&D). Standards for energy conservation are proposed for industry, transport and the household sectors. R&D efforts to improve energy efficiency and to create environmentally friendly technologies are advocated. Emphasis is also placed on the role of information and training to ensure proper energy management. The role of fuel substitution in achieving CO_2 stabilisation is stressed. These measures are proposed as part of a "no regrets" strategy because even if global warming proves illusory the likely effects of these measures are still desirable in themselves.

The EC Commission recognizes that these measures are unlikely to be sufficient in themselves to achieve the stabilisation target. They also propose the introduction of a carbon tax to bring about the required changes in economic behaviour to meet the objective of reducing emissions. This fiscal measure has attracted considerable attention elsewhere and is the focus of attention in the chapters in this Policy Paper.

The proposed tax is in fact a combined carbon/energy tax. The tax would be in the form of an excise tax levied on all fuels for energy purposes, excluding renewables but including large hydro-electric schemes. The break-down of the tax is in two parts, one on the energy content of a fuel and the other determined by the fuel's carbon content. Thus the same energy obtained from a fuel with a high carbon content (e.g. coal) would attract a higher tax than energy derived from a low carbon fuel such as natural gas. The level of the tax proposed is $10 per barrel of crude oil in 1990 terms, divided 50/50 on the energy and carbon components. This amounts to a mark-up of around 45 per cent on the 1990 world price of oil. It is proposed to introduce the tax in an escalating manner, $3 on the 1/1/1993 to be increased by $1 each year thereafter until the year 2000. See Appendix 5.1 to Chapter 5 for an example of how the tax would be calculated.

The revenues from the tax will accrue to the member states. Each member state can use these revenues at their discretion in various ways. Each must decide whether to earmark the revenues for energy and environmental expenditures or to achieve budget neutrality. To limit the macroeconomic consequences of the tax the EC suggest among a number of alternatives that the revenues be used to lower the tax burden on labour. Sectors which are energy intensive and exposed to international competition may receive exemption from the tax, particularly where competing nations do not undertake similar measures.

The introduction of such a tax, apart from its impact on the environment, would have significant consequences for the economic performance of the Community and of its individual member states. The likely impact of the proposed tax on fuel prices in Ireland by the year 2000 under the assumption of no behavioural change, using the ESRI macroeconomic model as described in Chapter 5, is shown in Table B.

This Policy Paper examines various aspects of this carbon tax measure, in particular its likely impact on the Irish economy. Chapter 1 by Denis Conniffe examines briefly the issues raised by global warming and he draws on historical events to highlight the dangers of over-reaction to the possibility of climatic

Table B: *Impact of EC Tax on Fuel Prices by 2000.*

Fuel	*%*
Coal (Residential)	22.7
Coal (Other)	100.0
Peat Briquettes	25.3
Petrol	5.9
Gas (Residential)	9.8
Gas (ESB*)	52.5

* ESB is the national Electricity Supply Board.

changes. Chapter 2 by Sue Scott describes the theoretical justification for the use of taxes rather than regulation in achieving reductions in carbon emissions. The distributional consequences of the proposed carbon taxes for Irish households are also examined. Lower income groups are shown to be more disadvantaged by the carbon tax because of the higher proportion of their income spent on energy and the type of fuels they consume. However, it should be possible to overcome these regressive effects.

Chapter 3 contains a survey by John Bradley of the various economic models that are available to analyse the impact of the proposed carbon taxes at an EC level. Given the nature of the environmental problem it is argued that there is an evident need for a long-term model with a global focus. Chapter 4 contains a paper by Burniaux, Martin, Nicoletti and Martins which makes use of such a long-term global model, namely the OECD GREEN model, to examine the implications of carbon taxes for the world economy. It is argued that proposals similar to the current EC proposals will have little significance for the global environment unless action is taken to adopt similar measures among the developing nations. Chapter 5 contains an analysis by John Fitz Gerald and Daniel McCoy of the macroeconomic implications of the proposed carbon tax for Ireland. The possibility of improved macroeconomic performance by using the revenues from the carbon taxes to reduce other more distorting taxes in the economy, such as those on labour, is examined. Chapter 6 contains commentaries by Frank Convery and by Donal De Buitleir on the preceding contributions.

Chapter 1

INTRODUCTORY REMARKS

Denis Conniffe

1.1 Introduction

The first point to be made in introducing this set of papers is perhaps obvious, but it needs to be made anyway. The ESRI is not an Institute for undertaking research on climatology and claims no expertise in the relevant scientific disciplines. However, over recent years, at least some experts on climate have become convinced global warming is occurring and that the root cause is the build up of atmospheric carbon dioxide caused by the combustion of fuels (IPCC, 1990). The European Commission has repeatedly signalled its concern and a directive aimed at stabilising, or even reducing, the production of CO_2 may not be long delayed (European Community, 1990).

The mechanisms specified could involve the introduction of quotas on the use of high carbon fuels or the imposition of carbon taxes to reduce the price competitiveness of such fuels. Indeed, a combination of a general tax on all fuels with special additional carbon taxes is quite conceivable on the grounds that it would encourage overall energy conservation and particularly discourage high carbon fuels. Such measures would affect the Irish economy in various ways. Energy is one necessary ingredient in the production of goods and services and an increase in its cost could alter not only the volume of production, but also its composition. The mix of the other inputs to production: raw materials, labour and capital, might also change. Again, the revenue raised by such taxation might well permit the reduction of other taxes, which would have further consequences for economic life. The full set of interrelationships is complex and so any proposed bundle of measures needs careful assessment in the context of implications for the Irish economy. This is where the ESRI has a role to play through its publication of this paper.

1.2 International Context

Perhaps the Irish could feel rather "hard done by" to have to subscribe to measures to reduce CO_2 at all. Most of the global CO_2 emissions are produced by more industrialised nations. In terms of CO_2 production per head of population, the USA has by far the highest figure in the industrialised world, see Table 1.1. Third world countries might well feel still more indignant and could even regard calls for international action on reducing CO_2 as tantamount to demanding that they stay underdeveloped. Now this is where the precise mixture of policy measures is so important. If the world does face disaster from global warming due to CO_2 production, then something must be done about it. But of the measures that would reduce CO_2, perhaps there is a subset that might not damage Irish economic prospects and might possibly even enhance them.

Table 1.1: *CO_2 Emissions in 1989*

Country	*Total (M.Tonnes of CO_2)*	*% of Total*	*Per Capita (Tonnes of CO_2)*
EC	2630	11.3	8.1
Ireland	29	0.1	8.3
Japan	1022	4.4	8.3
USA	5316	22.7	21.5
Rest of World	14404	61.6	2.8
World Total	23372	100.0	4.5

Source : European Commission, (1991).

There is another consideration also. If global warming is not actually occurring, or if it is, but not because of CO_2 production, then measures that damaged economic growth would be totally undesirable. I said initially that the ESRI is not an institution that can talk authoritatively about climate, but perhaps a few remarks might be in order on the statistical validity of at least some of the arguments that are used. Statements like "six of the warmest years recorded were all in the eighties" are made as evidence of a rising trend in global warming. Quite apart from definitional issues of "warmest" and "recorded", such a statistical sequence can hardly be supportive of a trend in global warming as against, say, a trend stationary but highly autocorrelated series, that is, where values depend on the previous values.

Even less impressive is the sort of argument that can be illustrated by the full page advertisement that appeared in the *Observer on Sunday* newspaper, on the 10th November 1991, paid for by the UK Department of Energy. It consisted of six photographs of wind damage caused in the "great storm" of 1987 in the UK and the huge headline - "Global Warming. We have been Warned". It is true that in the small print below this headline it was admitted that scientists are not yet able to say if the great storm was definitely caused by global warming, but the intended message was clear. What about the dreadful storm, so prominent in Irish folklore, the Night of the Big Wind (Coogan, 1969), on 6th January 1839?

1.3 Historical Perspective

Even if global warming is occurring, CO_2 may not be the causative factor. There have been climatic changes in the past it seems and not only in the long-term recurrence of Ice Ages. Farm land, walls and dwellings have been found beneath peat bogs in County Mayo, suggesting a drier climate three millennia ago. Even the history of Dublin suggests great variations. The Liffey froze so hard from December 1338 through to February 1339 that fires were lit on the ice and oxen roasted. A century later a succession of dry summers lowered the river so much that in 1452 it is said to have actually dried up for a period. But there were great floods in later years especially in the second half of the seventeenth century. In the first half of the eighteenth severe cold seems to have returned. There was a series of bitter winters and miserable summers commencing in 1739. The Liffey was frozen as badly as previously described from 29th December of that year until the 8th February 1740, people froze to death in the streets, and the military protected the trees in the Phoenix Park from firewood seekers. The bad summers led to crop failure and a horrific famine. Oddities built as famine relief projects still survive - the obelisk on Killiney Hill, Wonderful Barn at Leixlip, the Bottle Tower at Churchtown, etc. (Joyce, 1912).

This selective history of Dublin's weather does not prove anything about trends or the absence of them, but perhaps it warns against deducing too much from any short sequence of years. Now, I have no doubt that serious scientists, convinced of the reality of global warming and CO_2's responsibility, have employed sophisticated methodology on much broader data than one particular locality. However, they could still be wrong and I understand that other reputable scientists dispute their findings (Lindzen, 1991). So, while doing something to control CO_2 in case the causation and warming are real, it would be good if the measures taken are not undesirable if causation or warming are false. Such a situation may not be attainable for every country, but one of the objectives of this conference is to assess if it might be possible for Ireland.

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Chapter 2

THEORETICAL CONSIDERATIONS AND ESTIMATES OF THE EFFECTS ON HOUSEHOLDS

Sue Scott[1]

2.1 Introduction

This paper looks at the effects of the EC Commission's proposed carbon taxes and examines how they might influence income distribution and consumption of energy. Before describing this work, however, it will be useful to look into some theoretical issues which have an important bearing on our evaluation of the effects on people's welfare and should help us to judge the real worth of proposed measures.

We have at the minimum three important issues which, in ordinary terms, might be expressed in the following three statements:

1. The polluter should pay
2. We don't like taxes
3. The poor shouldn't suffer

Generally speaking, people would agree with these statements. We will look at each one in turn, the third statement giving the context for analysing the proposed tax's effects on households. A discussion of some of the issues arising is followed by conclusions.

2.2 The Polluter Should Pay

To disagree that the polluter should pay would be to imply that the victim should pay, or that no one should pay - in the latter case, the atmosphere would be a free waste disposal service and, being finite, subject to over-use. This is what we are actually witnessing in cases like acid rain among other problems and now, it is argued, in global warming.

Most goods and services are bought from owners through a market. The good being discussed in this paper is the atmosphere's capacity to assimilate carbon. The atmosphere however has five billion "owners" and as many users, who are the same people and who do not trade through a market. The "owners" are not owners in the sense that they can readily charge or exclude users, so of course the users do not

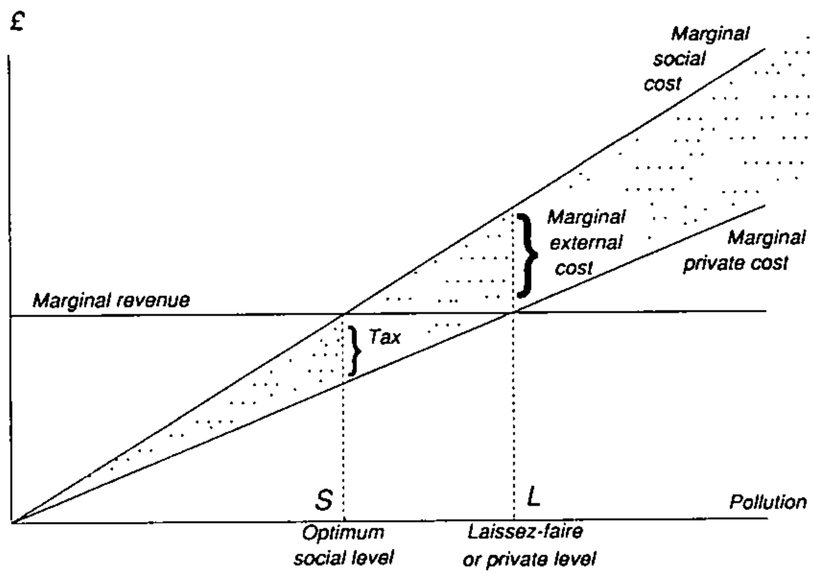
[1]The author wishes to thank colleagues John Fitz Gerald and Daniel McCoy for their support and comments on earlier drafts. Helpful advice was received from Frank Convery, Dermot Scott, Brian Nolan, Tim Callan, Chris Davies, Kevin O'Rourke, Conan McKenna, and colleagues on the editorial committee. Maura Rohan supplied librarial assistance and Pat Hopkins processed the drafts. The author is responsible for any remaining errors.

pay. Such a resource is a common property resource. Industrialists, householders and the rest can use the atmosphere's disposal services without paying although, and this is the important point, they are imposing costs on everyone.

In the case of carbon dioxide emissions, if the calculations predicting global warming are broadly correct, then fossil fuel use and other carbon-emitting activities impose costs, and possibly bestow some benefits, on everyone, albeit in the future. However, industrialists and householders naturally, unless acting in altruism, will base decisions as to levels of activity and fuel use on the costs and benefits that face them rather than be influenced by those facing society - that is they base their actions on the private costs and benefits and not on the social, or private plus external, costs and benefits. It is well known that maximum social efficiency is achieved at that level of activity where marginal social benefit equals marginal social cost. Take a manager of a firm when considering the scale of his operations, he will set output at the level which maximises profit. This will be the level where the cost of producing an additional unit of output equals the additional revenue earned from the sale of that unit.

The textbook diagram (see Figure 2.1), taken from Barrett and Walsh (1983), shows the optimum private level of activity, L, at the intersection of marginal revenue with marginal private cost - a unit more would incur a loss because cost would be greater than revenue, and a unit less would forego the opportunity for profit.

Figure 2.1: Optimum Private and Optimum Social Levels of Activity.



However, the efficient social level of activity requires the firm to pay additional costs which are external to the firm. External costs or externalities, which have to be estimated somehow, are the shaded area. The optimum level of activity is seen to be at a lower level S, the level at which marginal revenue equals marginal social cost.

In some cases, the victims and polluters might be able to negotiate a settlement between themselves as suggested by Coase (1960). Such a case would require that there be well-defined rights to clean air or disposal facilities and that the costs of negotiations be low. Where global warming is concerned these conditions do not hold nor are there clearly distinguishable victims and polluters. The laissez-faire market solution will therefore yield a too high level of polluting activity, at L.

It will be noticed that the optimum does not imply zero emissions and some external costs are incurred.

This is an example of how markets are not always good allocators of resources. Externalities which cannot readily be negotiated away are one problem for markets. Absence of owners who can charge or exclude users or negotiate is part of this problem as already mentioned. For example, a private company cannot charge for improvements to the atmosphere arising from its abatement activity. Other conditions for markets to allocate efficiently include the requirement that producers and consumers be well informed and that there be many of them, i.e. no monopolies. We will touch on these later.

The question is how to get everybody to the optimum social level - how to get the polluter to pay, either the external costs or pay ultimately to abate the emissions. Co-operation could get everyone there but the temptation to break ranks would be strong, especially if people expect that others will break ranks too. There is general agreement that this is a clear case for government intervention. It falls to governments to "repair the invisible hand" of prices, correcting a distortion which in the absence of intervention encourages over use of environmental services.

Broadly speaking there are two sorts of measures that governments can adopt. These are economic instruments and non-economic instruments. Economic instruments include taxation of emissions and tradeable quotas, though the latter spans the two measures. Non-economic instruments, on the other hand, include such things as regulations, standards, laws and quotas. Of course there is also the possibility of some combination of the two measures. We will concentrate our remarks below on the contrast between taxes and regulations. A further measure is exhortation but in the absence of the other two this is like asking people to be altruistic and act contrary to their own immediate advantage. Furthermore people who have not responded to exhortation reap a benefit from the responses of others. This is not to say that altruism is absent. The growth of green consumerism and activity at bottle banks bears witness to this but the scale may be small.

2.3 We Don't Like Taxes

This entirely reasonable sentiment has a theoretical underpinning which shows that most taxes impose an efficiency cost and leave the taxpayer with a loss which exceeds the value of the revenue which government obtains. This is aptly named "deadweight loss" by economists. Regulations on the other hand at least have the benefit of appearing clear and fair. For example, it would seem unthinkable in the UK during the Second World War to have imposed taxes or allowed prices to rise in place of rationing. However, during wars nations are dealing with sudden and temporary shortages. With pollution the aim is adaptation to an undistorted market solution which one wants to see persist. With carbon dioxide emissions in particular the aim is to move people along the line from coal to oil to gas to renewables. On the way they should be encouraged to exploit worthwhile energy saving technologies (that is, in the absence of direct carbon abating technologies), as well as shift to a consumption mix that is less intensive in goods and services having a high carbon content.

In any event, a deadweight loss may not arise if the tax in question, by reducing pollution, corrects a sub-optimal situation. The gain to society can outweigh the deadweight loss of the tax.

Of course we are used to the imposition of taxes aimed at discouraging harmful consumption such as the taxes on alcohol and tobacco. The recent lowering of tax on leadfree petrol or, more correctly, the relative raising of tax on leaded petrol, is somewhat similar. It is accepted and leaded petrol sales have now dropped their share of total petrol sales by some 25 per cent. However, the introduction of a large new tax on all energy may seem objectionable, not to mention inflationary. We have heard enough talk of tax packages and the tax system is complicated enough as it is. Some politicians seem to be worried that such tax proposals could be a liability, for example the Liberal Democrats in the UK have been considering their removal from the party programme, and governments tend to fall back on the usual regulations and exhortation.

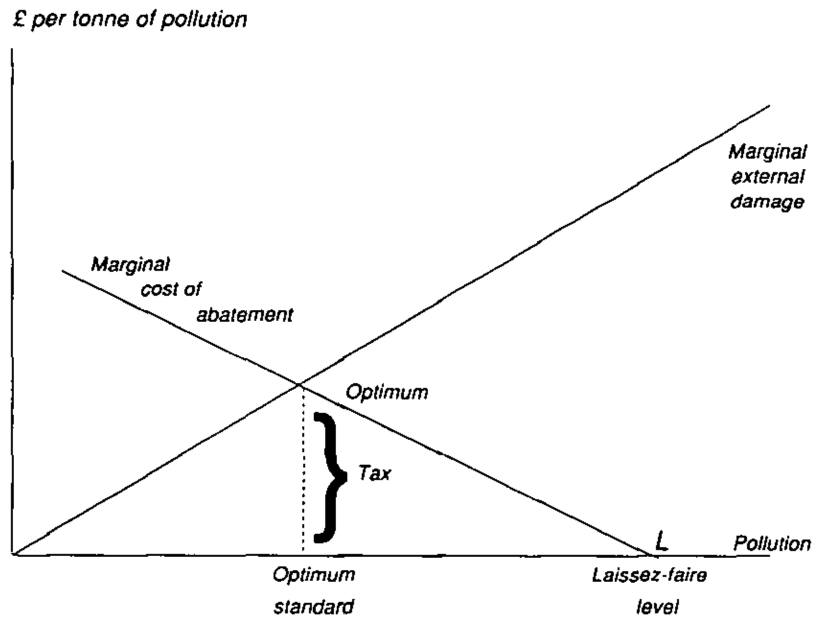
So if we don't like taxes we should see whether regulations would be better. It is worthwhile clarifying what are the advantages and disadvantages of taxes as opposed to regulations.

(a) It is possible that regulations which stipulate adherence by a certain date could evoke a faster response than taxes. This is the main advantage of regulations. By contrast taxes are "hit and miss".

(b) In order to achieve the optimum level of pollution a correct rate of tax has to be imposed. However in order to achieve the optimum by regulation, the correct standard has to be imposed. How to ascertain the correct tax rate or standard is difficult because one needs to know the money value of the damage caused by the pollution. To be precise, the tax per unit of activity needs to be set at the value of damage caused by a unit of activity at the optimum. Furthermore, there are situations where abatement is a possibility and desirable, or in the carbon dioxide case where investment in less energy intensive technology is an option. For a given level of pollution reduction, these possibilities can mean that the optimum does not require private benefit to be cut back so far. For a social optimum, investment in abatement or energy efficiency should take place to reduce pollution to the point where the marginal social damage of pollution equals the marginal cost of the investment. In other words, society should not spend more than it is gaining at the margin.

A higher level of investment in abatement or efficiency would give less pollution but the incremental costs would be more than the damage from the incremental unit of pollution. A lower investment would, in social terms, leave profitable pollution abatement unexploited. This tax which is imposed should be set at the marginal external damage at the optimum. This is very demanding in information, requiring knowledge of the costs of abatement and the damage costs, for all relevant incremental levels of pollution. However, the same information is required for the correct standard to be imposed.

Figure 2.2: Optimum Tax or Standard



In diagrammatic terms (see Figure 2.2), for increasing levels of pollution by a firm, marginal external damage rises as the atmosphere's assimilative capacity becomes tighter. Marginal abatement costs on the other hand rise the more pollution is reduced.[2] To produce zero emissions the costs could be very high, or infinite, but they will be lower at less stringent (i.e. higher) pollution levels. The laissez-faire level would be zero abatement, at L pollution (that is unless there were private or self inflicted damage by the firm, but we have abstracted from such extra considerations). To arrive at the correct tax or standard, the government needs economy-wide knowledge of the two schedules.

So there is not much to choose on the issue of information requirements between taxes and regulations in order to get to the optimum level. If you know that emissions are inflicting external costs then the introduction of some tax or some regulation is probably a move in the right direction. However, with regulations, if you don't have information for individual firms, some firms could incur huge costs of abatement.

(c) There is the view that pollution taxes are inflationary compared with regulations. This need not damage competitiveness provided that other countries impose taxes too, which is proposed. Within the EC, Ireland's GDP is slightly above average in terms of energy intensiveness and carbon intensiveness. For any individual firm, optimal regulations could impose the same abatement cost as optimal taxes because, as we saw in Figure 2.2, the optimum is the same, whatever the approach. However, of course, tax is still likely to be paid at the optimum, because there is still some pollution. It is also true that a monopolist could simply pass on the tax and continue polluting. Indeed pollution taxes, to be effective, require market conditions to be fulfilled and should ideally be applied in those instances. However, in our example of taxes on fuels there is *long-run* competition between fuels even if some individual fuels are supplied by monopolies. Though tax is still likely to be paid at the optimum, the extent of inflation, if any, needs to be estimated in the context of how the tax revenues are spent. The other fear that energy price rises could trigger a recession like that of the mid seventies after the OPEC price rise can be assuaged. On receipt of the revenues, our governments can be relied upon to spend them in one way or another, unlike OPEC which temporarily saved rather than spent the gains thereby depressing world activity.

(d) Unlike regulations, taxes allow the user and producer discretion in deciding how to reduce emissions. Regulations tend to be specific. Regulations are usually decided by the central authority which may not be in a position to know the particular circumstances of the individual. Standards are some-

[2]This rise in marginal abatement costs is in fact suggested in the sequence of Ireland's building regulations. The regulations introduced a decade ago entailed a reduction of energy requirements to heat new houses of some 40 per cent. The new regulations which are scheduled to become law in 1992 entail a further reduction of only 10 to 15 per cent, because the cheap savings were incorporated in the earlier regulations.

times applied to new equipment like new cars or new generating sets. However, by driving up the costs of the new equipment, they can actually cause polluters to postpone buying cleaner equipment.

(e) Taxes tend to be flexible. They can readily be altered in the budget. Regulations can provide more scope for corruption and changes could also be more disruptive to users and producers.

(f) With taxes there would be more reduction in pollution per pound spent on abatement. This is because different people have different incremental costs of abatement. Therefore, taxes encourage those whose incremental costs of abatement are lowest to do most abatement. Firms will abate where abatement is cheaper than the tax up to the point where, per unit of pollution, the tax equals the incremental abatement cost. Regulations, on the other hand, enforce the same amount of abatement on each firm even though different firms will incur different costs. So, if a tax achieves a reduction in pollution of 10 per cent, say, this will have been achieved in the cheapest way. That is firms with high abatement costs will choose not to abate but pay the tax instead. Firms facing low abatement costs will abate more than 10 per cent. Alternatively, impose regulations to require everybody to reduce emissions by 10 per cent and you have forced in the expensive abatement, and missed out on some cheap abatement. Using a recent example, had we forced the actual 25 per cent reduction in leaded petrol sales by means of some (non tradeable) quota imposed on each household, this could have imposed high costs, especially on owners of cars that cannot be converted. To achieve a given result, standard setting will incur greater abatement cost than taxes. If the problem of global warming requires a sizable response, this would argue for the more efficient instrument or, to quote Pearson and Smith (1991), "if anything, evidence that the carbon tax rate would need to be high strengthens the case for using cost-minimising methods of reducing pollution, and hence for choosing market mechanisms rather than the conventional regulatory approach."

(g) Taxes can be easier to enforce than regulations, though we know that there can be difficulties, as we shall see. In any event regulations also have to be enforced. If there is a penalty for non-compliance, the firm will pollute so long as private benefits are greater than the penalty and so it is tempted to pollute till they are equal, or beyond, if it does not expect to get caught. Monitoring is required and hence funds are also required to pay for the monitoring. Pollution regulations in Britain, for example, require inspectors to check that firms are not abusing the "let out" clause that they use the best available technology "not entailing excessive cost". Clearly the apparatus of inspection has to be of high calibre and be paid accordingly. In the absence of correct price incentives, regulations require us to act contrary to our inclinations, so we have to find the funds to pay people to watch us.

(h) In so far as people are always trying to reduce their costs, taxes tend to provide a *continuing* incentive to abatement and energy efficiency. With regulations on the other hand, the firm can pollute up to the standard with no penalty, so there is no incentive below the standard to search for less polluting methods. Taxes are a spur to innovate and an encouragement to research. Leave wrong price signals alongside standards, then the incentive is to get round the standard and research is not encouraged.

(i) Finally there is the public finance aspect of taxes. Pollution taxes bring in revenue. As should be clear from the above, this is not a reason for introducing pollution taxes, because they stand on their own merits. However, the revenue has to be taken into account when looking at the full story. The revenue gives the government the option, among several, of reducing other taxes, which is part of the subject of analysis by Fitz Gerald and McCoy in Chapter 5. The theory of optimal taxation shows us that the best combination of taxes is that which minimises the deadweight loss mentioned above. This is achieved through concentrating taxation on those items where demand is relatively unresponsive to price change. These are items with a low price elasticity of demand. We know that the demand for energy (and hence the production of emissions), though not totally unresponsive to price, is not very responsive compared to that for some other goods that are taxed. Therefore, potential welfare is increased by taxing energy in place of these other goods. Furthermore, society has a view as to the relative merits of pollution, which is considered a bad thing, compared to other taxable items, like consumption goods, work or employment, which would be considered to be good things. To quote Cairncross (1991), "rather than taxing good things, why not tax bad ones such as pollution?" . There may be a case in intuitive and theoretical terms for simply switching taxes from, say, labour to energy.

There could be a paradox here. Potential welfare is improved by concentrating taxes on items for which demand is relatively unresponsive to price, like energy. However, if energy demand is unresponsive to price then we will not achieve our aim which is reduced energy use. In fact there is no paradox in so far as the deadweight loss of a pollution tax is cancelled out by the gain to society, as mentioned earlier. In addition, long-run responsiveness may indeed be higher than we think (as well as long-run revenues). In the meantime with new energy taxation in place, Ireland benefits from the improved tax structure, coinciding appropriately with a temporary period of rapid labour force expansion, as well as a, hopefully, temporary period of high revenue requirements to pay debt interest. So, while in strict environmental terms the welcome revenue aspects of taxing an externality should not be a factor, incidental benefits may be such as to warrant such taxes in their own right.

To sum up then, while we do not like taxes, there are cases where they are to be preferred to regulations, which are the alternative. Also, taxation of emissions may be preferable as a replacement for some other existing tax. To a large extent the choice of approach will depend on one's priorities. If a fixed target has to be achieved, perhaps by a certain date, and at all costs (like in wartime), then regulations are the answer. If one wants a less costly move to a situation where the fundamental incentives are right and persisting, then taxes and other economic measures would be best. Taxes however, work well where market conditions prevail and so a wise course will be the imposition of the approach which is appropriate. In the case of global warming, probably a combination of carbon taxes and regulations would be needed.

2.4 The Poor Shouldn't Suffer

This is a major problem for carbon taxes. However, it should not be insurmountable. The problem stems from the fact that though households with low incomes spend less on energy in absolute terms, expenditure on energy as a proportion of income or total expenditure is greater. Therefore, a tax on energy will form a higher percentage of low incomes than of high incomes, which is regressive. We carried out an analysis on the impact for Irish households of the proposed EC carbon taxes. The final tax in the year 2000 is equivalent to $10 per barrel of oil. This adds up to £23.38 per tonne of oil equivalent (TOE) and £27.37 per tonne of carbon (see Appendix 2.1 at the end of this chapter).[3] The latter translates to £7.47 per tonne of CO_2. It will be seen that the imposition of the combined tax could amount to an average price rise for fuels of 15 per cent.

To help us to analyse the effects of these carbon taxes, the Central Statistics Office made available a table of fuel purchases in quantity terms (see Appendix Table A2.1) derived from the 1987 Household Budget Survey. From this source it is possible to derive the total amounts of energy purchased by each income group and the associated carbon dioxide emissions, shown in Figure 2.3.

Looking at the data more closely, it is evident that low income households have a double disadvantage. As shown in Figure 2.4, in addition to a higher proportion of expenditure going on energy, the fuels that they buy tend to be high carbon dioxide emitters (Appendix Table A2.2 gives greater detail).

In this exercise we are ignoring the phasing in of these new taxes over the years and simply assuming that the full tax is imposed immediately, onto the 1987 pattern of purchases. This probably gives a worse picture than is likely. In the first place there have been greater inroads by natural gas, which attracts a lower tax. Secondly there have already been some price rises in the meantime, though of course this tax could provoke the decline of some world fuel prices, natural gas excluded.

[3]A tonne of oil equivalent (TOE) is a common measure of energy defined as 10^7 Kilocalories. Conversion factors TOEs for various fuels are given in Table A2.5.

Figure 2.3: *Energy Purchases and CO_2 Emitted Annually per Household.*

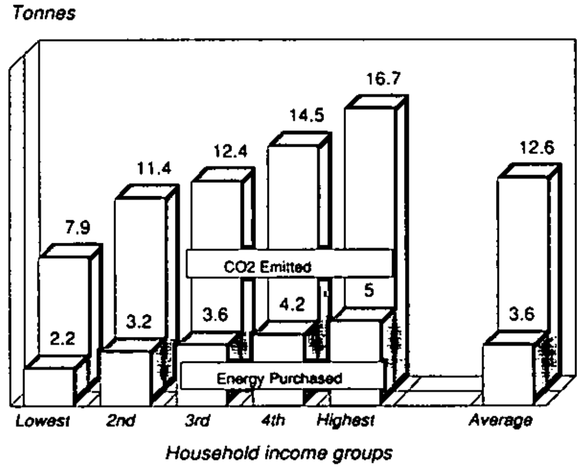
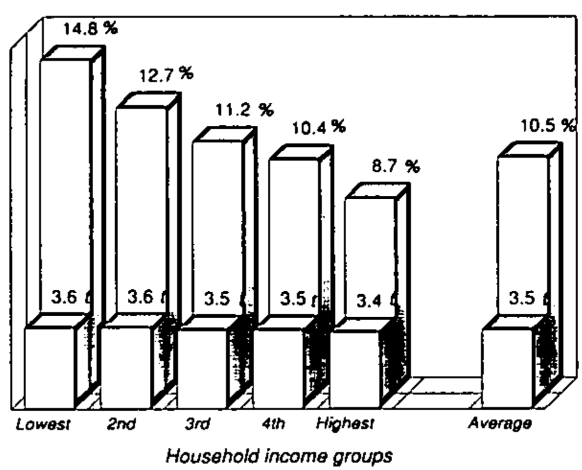


Figure 2.4: *Energy's Share of Expenditure and Tonnes CO_2 Emitted per TOE.*



This exercise also assumes that all the new tax is passed on to customers. So in the case of electricity, customers are assumed to pay the tax on the fuels used and on the carbon dioxide emitted in the generation of the electricity going to households. Table 2.1 below shows the household sector's annual energy consumption and carbon dioxide emissions, broken down by fuel.[4]

On the face of it, the emission factors suggest that per tonne of oil equivalent (TOE) bought, electricity is the most intense emitter, followed by coal, then the oils then the gases.[5] But of course per unit of *useful heat* enjoyed by the consumer, taking appliance efficiencies into consideration, an open coal fire can emit more than an electric fire, for example. Also, heating by electricity generated from gas can have twice the emissions of heating directly by gas. Meanwhile, the electricity factors are likely to decline as the ESB's fuel mix and technology adjust. On the other hand there may be a move to more efficient domestic coal burners. As of 1987 however, the average household consumed about 3.6 TOE and emitted about 12.6 tonnes of carbon dioxide per year.

Table 2.1: *Annual Energy Purchased and CO_2 Emitted, By Fuel.*

	Average Household		*All Households*		*Emission Factors*
Fuels	*TOE*	*t CO_2*	*kTOE*	*kt CO_2*	*t CO_2/TOE*
Anthracite	0.057	0.279	56	272	4.87
Coal + slack	0.944	3.491	921	3,408	3.70
Turf loose	0.460	1.995	449	1,948	4.34
Turf briquettes	0.133	0.577	130	564	4.34
CH oil	0.216	0.659	211	644	3.05
Paraffin	0.003	0.010	3	10	2.98
LPG	0.077	0.205	75	200	2.67
Electricity	0.893	2.989	872	2,918	10.26
Piped gas	0.087	0.180	85	176	2.07
Petrol	0.622	1.859	607	1,815	2.99
Diesel	0.112	0.343	110	335	3.05
LPG auto	0.003	0.007	3	7	2.67
TOTAL FUELS	3.606	12.594	3521	12,296	

Note: The figures for electricity include the fuels used in generation. The All Households figure for coal derived from the HBS is higher than that derived from other sources. These figures are not readily reconciled. t = tonnes, k = thousands.

[4]We sought advice on the emission factors which are also shown in the Table 2.1. In view of the wide range which we found in some factors, it should be noted that these are but one set and any others can be incorporated in this study.

[5]Electricity at the point of use is clean, it emits no carbon dioxide. However the production of electricity uses fossil fuels which emit carbon dioxide. In 1987, 55 per cent of Irish electricity generation depended on coal and peat, fuels which emit high amounts of carbon dioxide for the amount of energy obtained.

The imposition of the carbon tax gives the price increases shown in Table 2.2 which also shows the average household's annual carbon tax paid. We have not looked here at the effect of the tax on the prices of all other consumer goods. In particular we have not allowed for a rise in the price of public transport arising from the new tax on its fuel. However there is a case for not letting the price of public transport rise, not by exempting it from the tax however but by other means. Additional measures to enhance public transport's reliability and comfort might also be called for. In the absence of any adjustments on the part of consumers, the energy bill will rise by 15 per cent and annual tax revenue will amount to £178 per household and £174 million from all 976,304 households together.

The highest price rise is for loose turf. This is because the price of turf is quite low in the first place. The other solid fuels rise by 22 to 27 per cent. The main price rises after this are in central heating oil at 20 per cent, electricity at 16 per cent, gas at 10 per cent and petrol at 6 per cent. In the second column, the big revenue raisers are coal, electricity, petrol and turf.

Table 2.2: *Tax-Induced Price Rises and Annual Carbon Tax per Household.*

Fuels	*Price Rises* %	*C Tax/Household* £
Anthracite	22.6	3.42
Coal + slack	26.7	48.14
Turf loose	39.4	25.65
Turf briquettes	24.7	7.42
CH oil	20.0	9.98
Paraffin	12.0	0.16
LPG	6.3	3.32
Electricity	15.9	43.20
Piped gas	9.8	3.37
Petrol	6.1	28.43
Diesel	18.5	5.19
LPG auto	6.4	0.11
TOTAL FUELS	15.0	178.40

We know of course that consumers will adjust their consumption in response to these price rises, but it is not possible to give an accurate assessment of this adjustment. Potential adjustments to the 1987 purchases by the year 2000 are given in Table 2.3. The measures of responsiveness to price change calculated from the past could not go into the level of fuel detail and cross effects needed here. When the next Household Budget Survey is published it will be possible to make an attempt to calculate these. However, on the basis of experience it is possible to specify tentative estimates of responsiveness on which to base potential adjustments (see Appendix Table A2.3).

Table 2.3: *Potential Adjustments to Fuel Purchases and CO_2 Emissions.*

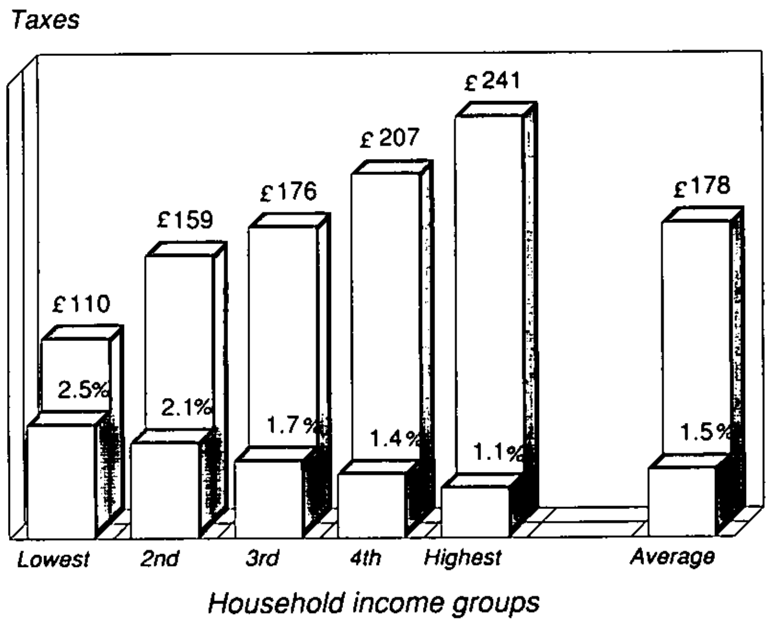
	Potential Adjustments			
	Fuel Purchases		*CO_2 Emissions*	
Fuels	*kTOE*	*%*	*kt CO_2*	*%*
Anthracite	-5.8	-10.3	-28.1	-10.3
Coal + slack	-101.9	-11.1	-377.2	-11.1
Turf loose	-3.0	-0.7	-13.2	-0.7
Turf briquettes	1.0	0.8	4.4	0.8
CH oil	-3.4	-1.6	-10.5	-1.6
Paraffin	0.1	2.7	0.3	2.7
LPG	-0.4	-0.5	-1.0	-0.5
Electricity	-5.1	-0.6	-17.0	-0.6
Piped gas	3.8	4.5	7.9	4.5
Petrol	-11.2	-1.8	-33.4	-1.8
Diesel	-6.1	-5.5	-18.6	-5.5
LPG auto	0.0	-0.1	0.0	-0.1
TOTAL FUELS	-132.0	-3.7	-486.4	-4.0

We are likely to see the major decline in coal and anthracite, of say a tenth, and the main rise in gas, of perhaps a twentieth. The overall decline in fuel consumption might be 3.7 per cent which implies a total responsiveness of -.25 per cent per one per cent price rise. The overall decline in CO_2 emitted is 4 per cent. As already stated, responsiveness may be a good deal higher than the figures we have used.

In order that the introduction of this carbon tax be socially, not to mention politically, acceptable it will be helpful if this revenue could quite simply be returned to households, but in some other guise. Figure 2.5 shows the very regressive pattern of the carbon tax, assuming no adjustments in consumption (see Appendix Table A2.4).

The two low income groups would be spending an additional 2.5 and 2.1 per cent compared to the average household which would be spending an additional 1.5 per cent only. These percentages are slightly higher than what would actually be the outcome because incomes and expenditure will rise in the meantime, but it is the pattern across households that is of interest. How can the authorities return the tax revenue in this pattern? Various channels can be checked out. A combination of reduced income tax and increased social welfare payments is a possibility, supplemented perhaps by the Family Income Supplement. However, the restriction to families with children and low take up of the latter reduce its effectiveness. A more suitable channel may be the lowering of VAT, which is itself mildly regressive. The standard VAT rate could be reduced by one to two percentage points, inci-

Figure 2.5: *Carbon Taxes Paid Annually (£ and % of Household Budget).*



dentally helping us to move more into line with EC rates. This would not be enough to compensate low income groups who could be helped by a reduction of the low rate of VAT of two or more points, though this could pose other problems. There would still need to be special attention paid to, for example, low income households with elderly inmates. This might be pursued through a rise in the Old Age Pension or perhaps through some targeted insulation and draught-proofing schemes and the like.

2.5 Issues Arising

As pointed out by de Buitleir in his discussion of this paper in Chapter 6, it might be informative to undertake the analysis of the tax's distributional effects on the basis of the household budget survey adjusted for equivalence scales. This takes account of the numbers of children in households and could give a more useful breakdown.

Concerning turf, we saw that its price would rise considerably and therefore its sales would fall. However, is it likely that a bigger quantity of private, as opposed to company turf extraction might be encouraged as a means of avoiding the tax? This could have serious implications for parts of the Irish countryside as we know it. Meanwhile it has been pointed out elsewhere that sales to the other big turf purchaser, the ESB, might profitably (taking BNM[6] debt repayment into account) be run down. The ESB's present turf burning will come under further pressure from carbon taxes so that we may see a case for bringing forward the planned alternative (post-depletion) uses of those bogs. Subsidies from electricity consumers to specific fuels, for example to nuclear and indirectly to coal in Britain and to coal in Germany and Spain, are clearly not exceptional, though social concerns could be better treated explicitly. Anyway with the imposition of carbon taxes, constructive thought would need perhaps to be applied more urgently to all possible alternatives for turf.

Current taxes on fuels are already high and it could be argued that the hydrocarbon taxes paid are enough taxes on energy without any more. Sweden, for example, which has already introduced carbon taxes, apparently cut in half pre-existing energy taxes prior to the new tax. Meanwhile, as mentioned, the full costs of coal and nuclear in other countries are not paid by the consumer. Obviously a job of rationalisation of the whole energy tax and subsidy area and related social concerns needs to be undertaken if one wants to avoid adding a new tax onto an existing muddle. The correct answer lies in the extent to which fuel use imposes other external costs. Feeney (1983), for example, showed that revenue from motorists' taxes easily covered the expenditure on infrastructure, whatever about certain types of heavy vehicle. However, vehicles impose other costs such as building decay, noise, congestion and so on. On the other hand there is the issue of competitiveness. So, in the absence of an up-to-date appraisal, it is not a foregone conclusion that motorists more than cover their costs, but that is not the only issue. It therefore remains to be seen to what extent, if any, existing hydrocarbon taxes should be reduced.

Up to this point, this paper has made the implicit assumption that improved energy efficiency would impose net costs on the individual or firm concerned. We talked about private benefit being cut back to achieve optimum social benefit. However, we frequently hear of companies and individuals making net gains from investment in energy efficiency with very short payback periods and that there are many more opportunities. These opportunities are strangely not taken up and yet there is apparently huge scope. Householders, for example, would prefer to install a new kitchen than insulate their house, even though the value of their house is raised more by insulation, in terms of reduced heating costs, than by the value of the new kitchen. This logical inconsistency has been well documented for example by the UK Department of the Environment (1991). To understand this behaviour, we have to look again at the conditions required for markets to function. We mentioned earlier that information was required. Energy efficiency is a complex area. For the householder to become informed he would need to do research, in his leisure time, which he values very highly. On the other hand, local showrooms can pleasantly provide the information he needs on new kitchens. The gathering of

[6]BNM stands for Bord Na Mona which is the Irish Peat Board.

information on energy efficiency is subject to large economies of scale and it should also be supplied by impartial bodies. Indeed carbon taxes could bring about a high public demand for the services of such bodies.

In particular there should be strong encouragement for the implementation of energy labelling - like energy labelling of appliances, thermal rating of clothes and in particular energy rating of houses. It is not clear why the building industry has not followed the motor industry, which tells you the car's miles-per-gallon (MPG), in setting an energy rating for their products. Perhaps the reason is that houses are much more complicated and that expenditure on energy is considered unimportant. In the UK, the National Home Energy Rating (NHER), designed to be understood by the general public, rates houses on a scale of 0 to 10, with 10 being the most energy efficient. Taking into account materials, structure, heating system used in the house and so on, the NHER programme can produce estimates of energy running costs and how these could be reduced by various measures. The UK's housing stock would be in the NHER range 4 to 5 or under, according to Archer (1991). A one integral point rise on the scale could reduce CO_2 emissions by 4 per cent. A rating scheme for Ireland is being developed at the National Irish Centre for Energy Rating (NICER). If energy prices rise, it will be in demand by sellers and buyers of houses as well as by householders wishing to improve their energy efficiency. Such a scheme could have an important role to play in helping the market to promote energy efficiency.

2.6 Conclusions

- We have seen that the environment is a common property resource and that laissez-faire can eventually lead to its over use.
- Governments can adopt two sorts of measures to reduce emissions: taxes and regulations. The latter are effective for achieving a specific target where the cost of achieving it is not especially important. However, taxes would achieve that level at lower cost.
- Taxes would promote a situation where the fundamental incentives are right and persisting. Taxes provide an incentive to innovate and go better than the standard.
- The imposition of taxes on emissions in place of some other taxes may improve the nation's welfare.
- The EC's tax proposals would, as expected, be regressive when applied to Irish households. Low income households spend proportionately more on energy and the fuels that they buy have a higher carbon content.
- There are several ways in which the tax revenues could be returned to households, though care will need to be taken to ensure the correct distribution in order to remove the regressive effect.
- In our calculations, the EC tax applied to households' fuel purchases raises energy prices by 15 per cent, adds £178 to the average household's annual expenditure on fuels and brings in £174 million in government revenue. Conservative estimates put the decline in energy consumption at 3.75 per cent and in CO_2 emitted at 4 per cent.

- Pre-existing energy taxes, subsidies and related social concerns need to be clarified. In particular, the potential impact on turf needs careful consideration. There could be pressure from the carbon tax to increase private turf cutting and decrease sales to the ESB.
- The taxation of transport requires close attention, bearing in mind external costs and competitiveness.
- The information needs of a well functioning energy market also require attention. Energy labelling of houses and appliances, for example, would be beneficial.

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Appendix 2.1: How the EC's Proposed Carbon/Energy Tax is Calculated

The Commission proposes a tax rate equivalent to $10 per barrel of oil. In order to smooth its introduction, the tax would start at $3 per barrel at the beginning of 1993 with an additional $1 per barrel applied in successive years until 2000. It is currently proposed that half of this tax be applied to the energy content and half to the carbon content of the fuel, though these proportions may be the subject of negotiation.

Using the conversions:

£ 1 = US$ 1.57 (approx., September 1991)
7.33 barrels of crude oil = 1 tonne of oil equivalent (TOE)
1 TOE of crude oil contains 0.854 tonnes of carbon,

The $10 tax can then be calculated, for the energy and carbon components, as follows:

Energy component: $5 per barrel =	£3.19 per barrel = £23.38 per TOE,
Carbon component: $5 per barrel =	£23.38 per TOE (as above) = £27.37 per tonne of carbon.

In ECU terms these translate to 30.5 ECU per TOE and 35.7 ECU per tonne of carbon (£1 = 1.3044 ECUs) and these rates have been used by the EC Commission in its analyses. They can be applied to any fuel provided one knows its energy and carbon contents.

The carbon component of the tax is sometimes expressed per tonne of carbon dioxide (CO_2) emitted rather than per tonne of carbon. When a fuel is burnt, the carbon contained in the fuel combines with oxygen in a fixed proportion, giving carbon dioxide. The weight ratio of carbon dioxide to carbon is 44 to 12, that is the carbon dioxide will be 3.666 times the weight of the carbon. So one tonne of coal, which is some 85 per cent carbon, on burning emits some 3.1 (i.e. 0.85 x 3.6667) tonnes of CO_2. The carbon component of the tax, £27.37 above, can therefore alternatively be expressed as a CO_2 component, namely £7.47 per tonne of CO_2 emitted. In summary the EC tax used in our studies is, in general terms:

Energy component: £23.38 per TOE CO_2 component: £7.47 per tonne of CO_2 emitted.

To aid computation of the tax for any individual fuel, a table of fuels' energy contents or conversion factors to TOE is given in Table A2.5. This enables the energy component to be estimated. The CO_2 component can then be calculated with the aid of the CO_2 emission factors, expressed per TOE, given in Table 2.1.

Examples of the tax, assuming it were imposed in 1992.

Gallon of Petrol

If the starting \$3 per barrel tax were imposed now (January 1992), this rate would be three tenths of the Commission's full \$10 rate given above. As the dollar fluctuates considerably one suspects that the initial definition of the tax expressed in dollar terms, the oil currency, will subsequently be replaced by a definition in ECU terms in order to avoid constant revisions. So in these tax calculations we maintain the dollar exchange rate of September 1991.

The \$3 tax would amount to (for any fuel):

Energy component:	£23.38 x 3/10 = £7.014 per TOE
CO_2 component:	£ 7.47 x 3/10 = £2.241 per tonne CO_2.

Given that 277 gallons of petrol = 1 TOE of petrol which emits 2.99 tonnes CO_2 (from Tables 2.1 and A2.5), then the tax per gallon is:

Energy component:	£7.014 / 277 = 2.53 pence per gallon
CO_2 component:	£2.241 x 2.99 / 277 = 2.42 pence per gallon

The total tax per gallon is therefore 4.95 pence. Given the current price of £2.84 per gallon, this tax adds 1.7 per cent to today's price. The full \$10 tax would add 10/3 times 4.95 pence, namely 16.5 pence, or 5.8 per cent.

40 kg Bag of Coal

Given that 1 tonne of coal = 0.665 TOE and that 1 TOE of coal emits 3.7 tonnes of CO_2, then the initial tax on a 40 kg bag of coal is:

Energy component:	£7.014 x 0.04 x 0.665 = 18.66 pence per bag
CO_2 component:	£2.241 x 0.04 x 0.665 x 3.7 = 22.06 pence per bag.

The total tax per bag of coal is therefore 40.72 pence. Given the current price of £7.90 per bag, this tax adds 5.2 per cent to today's price. The full \$10 tax would add 10/3 times 40.72 pence, namely £1.36, or 17.2 per cent.

It is seen that the carbon component is more significant than the energy component for high CO_2 emitting fuels, like coal and peat. The energy component is more significant in the case of natural gas and LPG.

Appendix Table A2.1: *Household Budget Survey 1987 Data, (Weekly Purchases).*

		Deciles of Gross Household Income[7]										
Fuel	*Unit*	*1st <£59*	*2nd ≤£93*	*3rd ≤£118*	*4th ≤£154*	*5th ≤£193*	*6th ≤£242*	*7th ≤£300*	*8th ≤£380*	*9th ≤£506*	*10th >£506*	*State Average*
Anthracite	kg	0.621	1.173	1.037	1.452	1.098	0.69	1.338	1.589	3.68	3.065	1.574
Coal + slack	kg	21.52	25.64	28.31	31.62	26.45	29.45	29.81	24.26	29.46	26.33	27.29
Turf loose	cwt	0.338	0.437	0.673	0.722	0.765	0.454	0.714	0.62	0.492	0.349	0.556
Turf briquette	bale	0.619	0.514	0.606	0.424	0.421	0.474	0.469	0.38	0.475	0.234	0.462
CH oil	litre	1.402	1.874	1.564	2.856	3.006	3.653	4.638	6.627	8.634	13.608	4.786
Paraffin	pint	0.179	0.305	0.17	0.241	0.055	0.035	0.117	0.121	0.074	0.089	0.139
LPG	kg	1.26	1.346	1.611	1.375	1.704	1.127	1.345	1.023	1.407	0.899	1.31
Electricity	units	26.18	37.49	44.16	56.53	59.22	69.01	76.54	84.33	89.02	105.57	64.80
Piped gas	therms	0.42	0.432	0.482	0.54	0.528	0.883	0.601	0.938	0.586	1.216	0.663
Petrol	£	1.9	2.933	3.831	5.911	8.124	8.472	11.59	13.14	15.43	17.708	8.903
Diesel	£	0.06	0.218	0.14	0.356	0.577	0.625	0.494	0.778	0.877	1.28	0.54
LPG auto	£	0	0	0.013	0.046	0	0.036	0.022	0.068	0.052	0.104	0.034

[7]Each decile contains 10 per cent of sample households ranked by income from the poorest to the richest.

Appendix Table A2.2: *Annual Energy Purchased, CO_2 Emitted and Expenditure on Energy, per Household.*

	Deciles of Gross Household Income										
	1st	*2nd*	*3rd*	*4th*	*5th*	*6th*	*7th*	*8th*	*9th*	*10th*	*Average Household*
Energy Purchased (TOE)	1.9	2.4	2.9	3.4	3.5	3.6	4.1	4.3	4.7	5.2	3.6
CO_2 Emitted (Tonnes)	7.0	8.8	10.5	12.3	12.5	12.4	14.5	14.6	16.2	17.2	12.6
t CO_2/TOE Purchased	3.64	3.61	3.64	3.59	3.55	3.46	3.50	3.43	3.43	3.33	3.49
Expenditure on Energy in £	560.3	719	854.8	1046.5	1165.9	1200.1	1434.3	1537.2	1736.4	1953.5	1220.8
% of Total Expenditure	15.4	14.4	13.3	12.3	12.0	10.5	10.9	10.0	9.5	8.1	10.5

Note: TOE = tonnes of oil equivalent, t CO_2 = tonnes of carbon dioxide.

Appendix Table A2.3: *Potential Responsiveness to Price Changes.*

	Anthra	*Coal*	*Turf loose*	*Turf Briquette*	*CH Oil*	*Paraffin*	*LPG*	*Electr.*	*Piped Gas*	*Petrol*	*Diesel*	*LPG Auto*
Anthracite	-0.5	0	0.05	0.05	0.05	0.1	0	0	0	0	0	0
Coal	0	-0.5	0.05	0.05	0.1	0.1	0	0	0.1	0	0	0
Turf loose.	0	0	-0.1	0	0	0	0	0	0	0	0	0
Turf Briquette	0	0	0	-0.1	0	0	0	0	0	0	0	0
CH Oil	0	0.05	0	0	-0.4	0	0	0.1	0.1	0	0	0
Paraffin	0	0	0	0	0	-0.4	0.05	0.1	0.1	0	0	0
LPG	0	0	0	0	0	0	-0.30	0	0	0	0	0
Electr.	0	0.05	0.05	0.05	0.1	0.1	0.05	-0.3	0.1	0	0	0
Piped Gas	0.1	0.05	0	0	0.1	0.1	0	0.1	-0.3	0	0	0
Petrol	0	0	0	0	0	0	0	0	0	-0.3	0	0
Diesel	0	0	0	0	0	0	0	0	0	0	-0.3	0.1
LPG Auto	0	0	0	0	0	0	0	0	0	0	0	-0.3

Note: Diagonal entries from the top left entry are estimates of a fuel's responsiveness to changes in its own price, off-diagonal entries are responsiveness to changes in other fuels' prices. For example, the own price responsiveness of coal is -0.5, i.e. a 10% increase in the price of coal would lead to a 5% decline in the quantity of coal consumed.

Appendix Table A2.4: *Annual Carbon Taxes Paid per Household.*

	Deciles of Gross Household Income										
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Average Household
Tax paid £	97.4	122.5	146.0	171.7	175.4	176.2	205.1	208.2	232.2	249.5	178.4
% of total expenditure	2.7	2.4	2.3	2.0	1.8	1.5	1.6	1.3	1.3	1.0	1.5
% of disposable income	4.1	3.1	2.7	2.6	2.2	1.8	1.8	1.5	1.3	1.0	1.7

Table A2.5: *Conversion Factors to Tonnes of Oil Equivalent (TOE) for Individual Fuels.*

Coal:	1 tonne	= 0.665 TOE
Anthracite:	"	= 0.7 TOE
Loose turf:	"	= 0.313 TOE
Milled peat:	"	= 0.186 TOE
Briquettes:	"	= 0.443 TOE = 80 bales
Central heating oil or gas diesel oil:	"	= 1.0334 TOE = 262 gals = 1191 lt
Paraffin or kerosene:	"	= 1.0556 TOE = 279 gals = 1268 lt
LPG:	"	= 1.1263 TOE = 428 gals
Petrol:	"	= 1.0650 TOE = 295 gals = 1341 lt
Residual fuel oil:	"	= 0.9849 TOE
Crude oil:	"	= 1.0226 TOE = 7.5 barrels
Jet fuel:	"	= 1.0533 TOE
Electricity	1000 kWh	= 0.086 TOE (at point of use)
	"	= 0.265 TOE (at generation)
Kinsale gas:	10^5 cu ft	= 2.5447 TOE = 1043 therms

Source: Department of Energy, fuel suppliers and other agencies.[8]

Definition: 1 TOE	= 10^7 kilocalories.
Gals	= Gallons
Lt	= Litres

[8]There are slight variations in conversion factors used by different agencies.

Chapter 3

MODELLING THE ECONOMIC EFFECTS OF ENERGY TAXES: A SURVEY

John Bradley[1]

3.1 Introduction

Economic activity has always carried with it external costs in terms of some undesirable changes to the environment. In previous times these costs were usually too small or too localised to cause global concern. However, with the acceleration in economic growth in the past hundred years, accompanied by a wider and more concentrated use of energy, environmental externalities have the potential of becoming too serious to ignore.[2]

In the light of recessions in the world economy in the early and late 1980s, the International Energy Agency forecasts that world energy demand will grow at an average rate of just under 2.5 per cent a year in the period 1988-2005, driving the price of crude oil (in constant 1986 dollars) from $24.40 in 1995 to $30 by the end of the century. Consequently, there is likely to be a background of continuing relatively low prices for conventional fossil fuels that will tend to militate against incentives to develop non-fossil fuels and to increase efficiency in the use of energy, such as characterised the period of the OPEC I and II oil price rises.

The "Greenhouse Effect" is certainly one of the most pressing of the environmental problems facing the world today. There is an obvious need to design sensible pricing policies that will provide agents with incentives to pursue goals like the switch to lower carbon fuels in the short term and to encourage the development of technologies to produce less CO_2 waste in the longer term. The proposed EC measures constitute an initial step in this direction. There is also a need to remove many of the existing market distortions which are operating against energy and CO_2 reduction in the economy. For example, Germany subsidises coal and Norway taxes low-CO_2 natural gas. Many EC countries have lower taxes on diesel than on petrol, but not for environmental reasons. The policy of developing heavy industry in the former communist block countries of Eastern Europe, regardless of cost and in the absence of any market mechanisms, has resulted in massive waste of energy.

[1]This paper was presented at the *Energy Tax in Europe* Conference, Amsterdam, 13 December 1991.

[2]An excellent readable non-technical over-view of these issues is available in the special supplement to the *Economist* magazine, *Energy and the Environment: A Power for Good, a Power for Ill*, 31 August, 1991.

Since the scientific knowledge of the physical processes involved in the "Greenhouse Effect" are not well understood, primary focus should obviously be on stimulating research into these fundamental scientific and technical issues in order to evaluate better the likely magnitude of the economic aspects of the environmental problems facing the world. However, the mere probability that some of the dire environmental warnings may come to pass is enough to drive a risk averse world into acting well before the catastrophe may arrive. Tools have been, and continue to be, developed which attempt to evaluate the costs and benefits of policies designed to reduce the world's emissions of GHGs. In the present paper we examine some of the key models that are being used in the European Commission and the OECD, and the results that emerge from them.

In Section 3.2 we first look at a recent report by Detemmerman *et al.* (1991), which used the four national macroeconomic models, called HERMES, for France, Germany, Italy and the United Kingdom (henceforth the EC "big-4"). This was a study of an energy tax (not differentiated by carbon content), both alone and in conjunction with accompanying energy conservation and other fiscal measures.

In Section 3.3 we examine a report by Capros *et al.* (1991), which uses the EC MIDAS energy/economy model in a study of the effects of an energy tax (both differentiated and undifferentiated by carbon content), with and without specific energy conservation measures, and with and without endogenous (i.e., relative price sensitive) determination of investment by energy utilities. Once again, results are available for the EC "big-4". We also comment briefly on a report by COHERENCE (1991) which uses the EC's EFOM energy-environment model in a study of non-fiscal options for CO_2 reduction.

In Section 3.4 we briefly review some recent work by the OECD in the field of CO_2 analysis. This has involved the development of a large-scale computable general equilibrium (CGE) model, called GREEN, which covers the whole world in six sub-regions, and is specifically designed to permit analysis of long-term economic effects and subtle issues such as the international trading of emissions permits. This is very much state-of-the-art in applied economic global modelling and its results will undoubtedly be highly influential on OECD governments in the design of global policy on CO_2. Details of this work are the subject of Chapter 4 by Burniaux *et al.*

In addition to its own CO_2 modelling work, the OECD is co-ordinating a project on comparing and contrasting other global models, mainly US based, for CO_2 analysis. The aim of this project is to attempt to reconcile (or at least explain away) the very different results obtained by the various modelling groups. We comment on the preliminary results of this work in Section 3.5.

Finally, in Section 3.6 we draw some conclusions and examine what lessons there are to be learned from past work which might help improve our present research efforts.

3.2 HERMES for Analysis of CO_2 Policies

The structure of HERMES was designed in the immediate aftermath of the OPEC-II oil-price shocks in 1979 see d'Alcantara and Italianer (1982). In settling on a structure, and on the level and nature of sectoral disaggregation, a delicate balance had to be struck between:

(a) having a sufficient level of detail to allow analysis of specific sectoral effects of macroeconomic consequence and a sufficiently refined treatment of energy and

(b) keeping the national models sufficiently compact and manageable. The key dimensions eventually chosen were as follows: nine production branches; eight energy types and fifteen consumption categories.

In terms of its treatment of energy and production modelling, HERMES was in 1982, and *still* remains today, among the most advanced macroeconometric models available and operational. Before looking at some published results of CO_2 analysis using HERMES, it is useful to recall the three crucial areas of the model which make it appropriate for the task of energy-related analysis and which largely determine the results of policy shocks such as would be administered by a CO_2 tax.

HERMES: Aggregate Energy as a Factor Input

The production function used in HERMES has four factor inputs: capital or investment (K), labour (L), aggregate energy (E) and other material inputs (M). In actual fact, many of the national HERMES models are estimated with only three factor inputs (KLE), due to data availability problems and estimation difficulties. Briefly, the original specification called for a vintage putty-clay capital input and a generalisation of the CES production function. The supply structure of HERMES was derived in a two-stage process:

(i) In stage one it is assumed that firms derive their long-run factor demands at the margin as the result of a process of minimisation of the expected costs of production, while the rigid factor proportions associated with past investment vintages are used to generate profitability conditions to determine scrapping rates of old capacities. In practice it proved impossible to operationalise the formal scrapping model and more *ad hoc* approaches were adopted.

(ii) In stage two the level of "planned" or "capacity" output is determined by maximizing a modified profit function, taking into account production "bottle-necks". For a further examination of this stage, see Bradley, (1990).

For the analysis of energy tax changes, the crucial information that we need to know from empirical estimates of the HERMES factor demand system is how sensitive the factor demands are to changes in energy prices, or, more technically, the values of the *ex ante* marginal Allen partial elasticities of substitution, the own price elasticities of energy demand and the marginal cross-price elasticities. A readily accessible source of this information for cross-country comparisons is available in a report by Italianer (1986), pp. 87-91, who rightly refers to the equations for the marginal technical coefficients (i.e., the factor demand system) as "the heart of the putty-clay production model". In that report there are two inner CES bundles: K-E and L-M, the outer KE-LM function being Cobb-Douglas.

Using the empirical results available at that time, Italianer found that in the intermediate goods branch (Q), capital and energy were complementary (Ireland being the only exception); in the capital goods branch (K) substitution possibilities existed only in three of the eight countries; in the consumer goods branch (C), all countries were found to show complementarity. Italianer concluded that "on a European scale, capital-energy substitution possibilities only exist in the K sector, and then only for some of the non-energy producers".

Turning to the own-price elasticities, Italianer concludes that "the spread of (negative) own-price elasticities is very large among countries, branches and factors and systematic *European* tendencies are hard to detect". Energy was found on balance to have the highest own-price elasticities, ranging from -1.19 for the Italian K sector down to -0.20 for the French Q sector. The anomalous German results were ignored.

These results, and more recent ones, beg the question as to what explains the wide diversity of economic behaviour throughout an EC that should by all accounts be evolving towards greater economic homogeneity.[3] Do they arise from fundamental differences in the energy supply or demand structures in the different EC members states? If so, it would be wise to relate these HERMES results to insights obtained with the other EC models like MIDAS and EFOM, and with other international research findings, in an effort to explain them.

Or could they simply indicate a possible lack of robustness in such production models, and require a more systematic search for stable and credible models before they are used in a sophisticated tool like HERMES for serious CO_2 analysis? It might be wise to replicate the approach used in the International Monetary Fund's world model, MULTIMOD, which is partially estimated with *pooled* data from selected groups of countries which are expected *a priori* to be relatively homogeneous see Masson, Symansky and Meredith (1990). By controlling thus for inter-country heterogeneity which is deemed unimportant or random, a more direct focus can be made on policy issues of vital concern. These are issues that are at the centre of all applications of models by policy analysts, and must be tackled in an honest and direct way in order to reinforce the *credibility* of model-derived policy advice.

HERMES: The Inter-Fuel Substitution Module

Energy was treated as an integral part of the original HERMES design and it was handled both as a factor input (the aggregate "E" factor input used above) and in disaggregated form as eight energy subcomponents. The main purpose of the

[3]The great difficulties in deriving good energy price data should also be noted, and may have caused problems with the statistical estimation.

energy submodel was to allocate the aggregate intermediate energy demand over its different products. Inter-energy substitution is allowed in the sub-model and the optimal energy product mix is a function of relative energy prices. Briefly, the modelling process is treated as follows.

The aggregate production function for each branch is assumed to have all the necessary properties to permit a two-stage optimisation process, i.e.,

(a) the firm first chooses the optimal energy input mix within the aggregate energy input, and

(b) the firm then optimises the energy aggregate "E" itself, jointly with determination of the other factor inputs, a stage already covered above.

The necessary regularity conditions assumed ensure that there exists a homothetic function that aggregates the eight energy types $\{E_1,...,E_8\}$ into the energy aggregate, i.e.,

$$E = E(E_1, E_2, \ldots, E_8)$$

Dual to the energy input function E(.) is an energy cost function

$$C = C(p_1, p_2, \ldots, p_8)$$

where the p's represent the different energy prices. This may be written in the form

$$C = E.c(p_1, \ldots, p_8)$$

where c(.) is the unit cost function. Given the assumption of homotheticity (i.e., the optimal budget shares are independent of the level of aggregate energy), a translog unit cost function may be written in the form

$$\log(c) = \alpha_0 + \sum_{i=1}^{8} \alpha_i \log(p_i) + 0.5 \sum_{i=1}^{8} \sum_{j=1}^{8} \gamma_{ij} \log(p_i) \log(p_j)$$

Cost minimisation yields the following energy share equation:

$$\frac{p_i E_i}{\sum_{j=1}^{8} p_j E_j} = S_i = \alpha_i + \sum_{j=1}^{8} \gamma_{ij} \log(p_j)$$

where the theoretical requirements of adding-up, linear homogeneity and symmetry place various restrictions on the parameters α_i, γ_{ij}.

It needs to be said that in spite of their crucial role in determining the outcomes of carbon taxation policies, econometric estimates of inter-fuel elasticities of substitution are scarce and not very reliable. A recent survey by the OECD (1991a), found that estimates for European countries suggested that long-run substitutability between electric and non-electric energy might range from 0.9 to 1.5. At a more disaggregated level, substitution possibilities between different kinds of fuel seem to be substantial in both the US and Japan, with the possible exceptions of petrol and electricity and, especially, natural gas and coal.

However, in the context of energy modelling in general, the OECD report sounds a warning, which is very applicable to the HERMES model in particular (OECD, 1991a, page 47):

> The economic interpretation of (inter-fuel elasticity) estimates is not always straightforward. The econometric analysis of substitution possibilities among different kinds of energy inputs is usually based on the assumption that energy and capital are weakly separable in production. This means that firms are assumed to choose first a cost-minimising fuel-mix and subsequently choose the optimal capital-energy bundle.
>
> Strictly speaking, this only makes sense in situations where "dual-fire" or "multi-energy" technologies are available. Otherwise, substitution possibilities depend on the installation of new capital and, therefore, separability breaks down. Since firms having multiple power-generating technologies generally represent a small fraction of the data on which most econometric studies are based, estimation results should be considered with caution.

For the two studies at hand at the time of writing which use HERMES for CO_2 analysis, this criticism applies only to the Belgian model (Bureau du Plan, 1990; Bossier and de Rous, 1992), which contains an inter-fuel substitution module. In the multi-country exercise (reported in Detemmerman, 1991), the EC "big-4" country models do not have such a module, implying a maintained hypothesis of *zero* inter-fuel substitution possibilities. In fact both studies may not differ greatly since the inter-fuel substitution elasticities, as estimated in the Belgian and other energy sub-models, tend to be quite small.

HERMES: The Consumer Demand System

Total private household consumption accounts for over 60 per cent of GNP in most western economies and is an important economic mechanism within any macro model. In the HERMES model it was felt desirable to disaggregate private consumption into fifteen commodity groups since the composition of demand is important in explaining structural change in the medium term. In addition, the availability of disaggregated consumption permits a more accurate modelling of the indirect taxes which bear on consumption bases.

Three of the fifteen consumption categories are energy related:

(1) Fuels for domestic use
(2) Power for domestic use
(3) Fuels for personal transportation

The implicit assumption is made that one may separate the consumer's decision on what proportion of income to consume from the decision on how total consumption expenditure is allocated over the whole range of consumer goods. The former decision is modelled by an aggregate consumption function while the latter is handled by an appropriate consumer demand system. The separability assumptions resulting in a two-stage decision process used here are very similar to those used in the energy submodel treated above.

The theory of consumer demand is well developed and suggests constraints on consumer behaviour which allow one to reduce the difficulties of the subsequent estimation process. Various different approaches have been adopted, including the so-called Rotterdam model (Barten, 1968), the linear expenditure system (Stone, 1954), and the unfortunately-named Almost Ideal Demand System (AIDS) model (Deaton and Muellbauer, 1980). There has been relatively little difficulty in assembling the necessary disaggregated consumption data for the different EC countries. However the number of years data available (about twenty-five years, starting in 1960) is usually insufficient to permit robust estimation with the full fifteen consumption categories. Estimation with fewer categories often yields better results. Summary results for eight of the EC countries are given in Italianer (1986). In practice the individual elasticities have been found to lack robustness and have provided only limited insight into the effects of large relative price changes on, for example, energy consumption by households. Consequently, it would be unwise to rely on these demand models too much.

What the Empirical HERMES Applications Show

For the EC "big-4" study (Detemmerman, 1991), in the absence of an inter-fuel substitution module, the only way to reduce CO_2 emissions is to reduce energy consumption. A tax of 20 per cent on the aggregate energy price is applied and the result compared to a scenario where the tax is zero. The following scenarios are simulated:

(i) No accompanying measures.[4]

(ii) Redistribution of CO_2 tax revenue to fund energy-conserving investment subsidies

(iii) Redistribution of CO_2 tax revenue to fund tax cuts such as
(a) employers social security contributions
(b) direct personal taxation

(iv) Combination of (ii) and (iii)

In terms of their effects on GDP (a broad welfare measure) and energy intensity of GDP, the summary results are shown in Table 3.1 below.

In case (i) the battle between the negative income effect of the tax rise and the mildly positive substitution effect (as firms try to substitute the now dearer energy factor for the relatively cheaper capital and labour and households shift their consumption pattern away from energy) is won unambiguously by the former. Such effects are well understood and mirror similar simulations made in the evaluation of oil price shocks in the 1980s, where the price rise originated from the behaviour

[4]In a model with endogenous government borrowing and public debt accumulation, the "no accompanying measures" scenario is equivalent to a run-down of the debt and/or an accumulation of further surplus. This will be a partially self-reinforcing process if public sector debt interest payments are also endogenous. The intertemporal aspects of such a policy stance are not without interest.

of the price-setting OPEC cartel rather than from energy taxes (Helliwell and MacGregor, 1983). What is also very interesting is the differences that emerge between the "big-4" in their ability to contain the inflation shock (France being the most inflation prone, Germany the least). It would be worthwhile to investigate further the model mechanisms (mainly wage and price determination) that give rise to this result.

In case (ii) a situation is simulated where energy-saving investment (e.g., retrofitting of old plant, etc.) is carried out by firms and is of such a nature that there is no consequential effect on capacity or on capital-labour productivity. The model is calibrated so that an increase in investment of 1 per cent of GNP is forced to produce energy savings of 3 per cent per year. An initial simulation (not shown in Table 3.1) assumes that firms finance the extra investment themselves, and this very Keynesian shock converts the case (i) fall in GDP to modest rises, but results in less energy saving (as a per cent of GDP).

The simulation reported in Table 3.1 assumes that the entire CO_2 tax revenue is devoted to funding a subsidy to industry for the above energy-saving type of investment. The Keynesian stimulus to growth is apparent and curiously is actually slightly less than the privately funded case (compare Tables 4 and 5 in Detemmerman, 1991). The eventual energy savings are approximately double those in case (i).

In case (iii)a the CO_2 tax revenues are redistributed as cuts in employers social insurance contributions and in case (iii)b as cuts in personal income tax. The effects are broadly similar, although the model mechanisms underlying them are quite different. In both cases there is a reversal of the negative GDP effect, combined with less energy saving than in case (i).

Finally, in case (iv) a mixture of the 20 per cent CO_2 tax combined with an increased investment subsidy and employers and employees tax cuts is simulated, and leads to no loss of GDP (indeed a modest gain in the medium-term), less inflation and greater energy savings.

Four points strike one in evaluating this type of research:

(a) First, more information is needed about the way in which investment leads to energy savings via factor substitution and development of new technologies. A formal parametric method of modifying the production function in a way that gives diminishing returns to investment would allow a sensitivity analysis to be carried out. If such information exists, as well it may, it would be worthwhile to incorporate it into the HERMES framework of analysis.

(b) Second, since national models as large as HERMES are likely to be simulated in isolation from a global model, is there a way of neutralising the shifts in competitiveness that are inappropriate in a world acting in co-ordination? If the linked HERMES system were easy to operate and maintain, this issue would not arise. However, the opposite appears to be the case, and the linked model system requires enormous resources in use. A "second-best" approach, stopping well short of a full linkage of the national models, might be useful.

Table 3.1: *Summary Results from Detemmerman et al, 1990 Scenarios (i) - (iv)*

		Initial Year (1991)		Final Year (1995)			
		GDP	*Energy*	*GDP*	*Energy*	*Prices-91*	*Prices-95*
(i)	GR	-0.87	-3.12	-0.97	-5.59	2.04	2.71
	FR	-0.72	-2.86	-1.30	-4.31	2.63	5.46
	IT	-1.10	-2.60	-1.34	-4.78	2.37	3.74
	UK	-1.44	-3.87	-2.12	-6.08	2.65	4.01
(ii)	GR	0.16	-3.81	0.11	-10.66	2.16	3.05
	FR	0.84	-2.93	0.61	-8.41	2.47	5.84
	IT	0.18	-2.68	-0.36	-7.00	2.90	4.22
	UK	0.10	-4.54	0.18	-11.64	2.81	4.56
(iii)a	GR	-0.22	-2.89	0.38	-4.90	1.29	1.77
	FR	-0.50	-2.72	0.38	-2.96	2.27	2.16
	IT	-0.16	-2.23	0.66	-2.72	2.17	2.44
	UK	-0.45	-3.30	0.08	-4.46	0.74	3.10
(iii)b	GR	0.02	-2.28	0.52	-3.80	2.10	3.12
	FR	-0.07	-2.38	0.18	-3.13	2.50	5.66
	IT	-0.41	-1.85	0.58	-2.12	2.75	4.24
	UK	-0.30	-4.32	-0.05	-4.19	2.38	4.57
(iv)	GR	-0.09	-3.20	0.27	-7.15	1.53	2.26
	FR	-0.15	-2.79	0.46	-4.77	2.36	3.39
	IT	-0.02	-1.80	0.18	-4.86	1.98	2.81
	UK	-0.31	-3.63	0.11	-6.45	1.31	3.51

Note: Figure for GDP is percentage deviation from benchmark;
Figure for Energy is percentage of GDP;
Figure for Prices is percentage deviation of Consumer Prices from benchmark.

(c) Third, since CO_2 policy analysis consists in administering a series of fairly standard shocks, it would be useful to have to hand a summary of the multiplier properties of the models where the stylised differences between national economies were made explicit *ex ante* rather than being discovered in passing *ex post* in the middle of an already very complex piece of policy analysis. In this way one would have a clearer understanding of the stylised similarities and differences between the EC economies (e.g., reaction to inflationary shocks, policy reaction functions, degree of openness, etc.).

D

(d) Finally, a comparison between the Detemmerman, 1991 study and the Belgian Bureau du Plan, 1990 work should be instructive. It should permit one to evaluate whether the addition of an inter-fuel substitution model and a fuel-specific carbon tax leads to qualitatively different results to the simpler analysis described above. Unfortunately such a comparison is not possible on the basis of previously published results but research presently under way will permit cross-county comparisons to be made.

3.3 MIDAS and EFOM for Analysis of CO_2 Policies

To an economist who is a non expert on energy matters there appears to be two polar or opposing types of model used in energy-related research. The first is primarily an economic model, but incorporates energy in an economically meaningful way. HERMES is a typical example of such an energy-economy model. Economists and economic policy analysts are comfortable with such tools, feel they understand and control them, and use them to extend and quantify their thinking. They permit one to study the "macroeconomics" of energy issues, and have reasonably transparent "micro-foundations" based on familiar notions of constrained utility maximisation by firms and-households. Using the term of Capros *et al* (1991), such models are used in "top-down" analysis.

The second type of model is primarily energy oriented, often being a description of a nation's energy system in mathematical form and in all its technical detail (e.g., construction of the load duration curve, plant utilisation scheduling and tariff determination in electric power planning). The MIDAS model mainly falls into this category, as does the EFOM system. The economy, or economic ideas, are often in the background of these models (so far in the background in the case of EFOM as to be out of sight of the concerned economist reader).

Engineers are comfortable with such "energy" models and use them to study the "microeconomics" of energy issues in a "bottom-up" form of analysis. To economists, however, they are like "black boxes", and their results have to be taken on trust, which is an unsatisfactory situation. Furthermore, their use is often in a very partial equilibrium context, where key economic magnitudes are set exogenously and a form of conditional energy sub-optimisation carried out. For example, MIDAS takes certain key economy measures as given and models energy demand and supply in great detail, computing a set of energy prices and the resulting energy balances. The different energy technologies in MIDAS are calibrated econometrically from historical data. More recently, work by Karadeloglou (1992) shows how HERMES and MIDAS can be integrated and run as a joint inter-linked system.

Capros *et al*. (1991) have used the MIDAS model to examine CO_2 tax issues for the EC "big-4" and their work potentially provides a way of cross-checking and evaluating the HERMES-based studies. Using the enormous energy detail available in MIDAS, they have implemented a CO_2 module which relates CO_2 emissions very precisely to the different fuel sources and have modified the energy price determination with a CO_2 tax mechanism. Taking the economic assumptions contained in the EC study *Energy 2010*, a reference scenario for CO_2 emissions is prepared out to the year 2005.

A series of policy changes is now administered to the MIDAS model in the case where energy capacities and related investment are exogenously set, consisting of:

(a) A range of CO_2 tax rates from \$5 to \$40 per barrel
(b) A range of undifferentiated energy tax rates from \$5 to \$40 per barrel
(c) CO_2 taxes with formal accompanying energy saving measures

The above three policy changes are also run for the case where energy investments are endogenised and made sensitive to relative fuel prices. In every case the shocked result is compared to the unshocked benchmark and the potential reduction in CO_2 evaluated together with the marginal efficiency of the tax.

Energy taxes affect MIDAS in three main ways:

(a) The more expensive heavy-emitting CO_2 fuels will tend to be substituted out in favour of lower emitting CO_2 fuels;
(b) Total energy demand will fall as the price rises, depending on the elasticity of demand incorporated (parametrically) in MIDAS;
(c) The structure of energy supply may change in the longer term as the altered price system provides investment incentives, although this mechanism can be switched out.

In evaluating the MIDAS results, the partial equilibrium nature of the simulations needs to be kept in mind, i.e.,

(1) Key non-energy macroeconomic activity aggregates are not effected by the tax but are set exogenously;
(2) No explicit feedbacks are allowed for the redistribution of the CO_2 tax revenues although an implicit redistribution mechanism is perfectly compatible with point (1) above;
(3) No non-energy price effects are taken into account although it would not be very difficult to include them.

Some broad conclusions are drawn from the range of simulations presented in Capros *et al.* (1991).

(a) A CO_2 tax is not sufficient by itself to stabilise emissions by 2005 when power generation investment is exogenous, but will be successful when investment is made sensitive to relative prices. This is explained by the low energy demand elasticities typically incorporated in MIDAS.
(b) The marginal efficiency of the tax falls as the tax rate rises and as the easily substituted heavily emitting CO_2 fuels are progressively cut

(c) A CO_2 and an energy tax have almost identical effects on CO_2 reduction, a finding that is confirmed by the Belgian Bureau du Plan, 1990 study. This is a somewhat short-term result and is reversed in the longer-term CGE modelling context (see below) where the need to discriminate against coal is emphasised in the carbon tax.

(d) The individual country results can vary greatly, and this can be traced back to the different electrical power structures (e.g., the importance of nuclear power in France).

(e) If the CO_2 tax is accompanied by a range of energy saving measures (such as the EC MURE, FRET and DERE projects), then the potential reduction of emissions is greatly enhanced and even ambitious targets can be achieved.[5]

The EFOM-Environment system is also in the engineering tradition, being a linear programming model representing the behaviour of the energy producing and consuming sectors with a very high level of institutional detail. Its strength lies in the ability to help identify the least cost mix of technological options that allows CO_2 emission constraints to be met.

The basic finding of the COHERENCE (1991) study is surprisingly optimistic and up-beat:

> Even without any constraint on CO_2 emissions, the least cost development of each national energy system would lead to the stabilisation of CO_2 emissions by the year 2000 at 1990 levels within the EC. The key option to achieve this short-term stabilisation target is provided by energy conservation, especially in end-use sectors where the potential for further cost-effective energy efficiency improvements has proved to be large.

It is, however, acknowledged in the report that:

> a detailed analysis of the economic instruments such as taxation and subsidies capable of encouraging the full implementation of those options identified to be cost-effective would represent an essential complementary analysis to (the EFOM) study.

As an economist I have some difficulty in accepting the EFOM optimism.[6] For example, one of the best possible incentives to stopping smoking is provided by clear medical evidence that it kills you. In many countries the tax system and other restrictions have long been used to penalise consumption of tobacco. Nevertheless, consumption of tobacco still remains stubbornly high and tastes are slow to change. In the case of energy, if the less developed countries (LDCs) are

[5] *MURE* is the energy saving programme in the domestic and transport sector. *FRET* is for the reduced CO_2 emission technologies for power generation. The *DERE* programme concerns the use of renewable energies in electricity production.

[6] "Environmentalists understandably yearn to give energy efficiency a shove in the right direction. Investing in energy efficiency, they point out, almost always yields a higher rate of return than building new power stations. Economists, by contrast, tend to regard energy efficiency like the man whose friend draws his attention to a £20 note lying on the pavement: "It can't be", he says. "If it was, somebody would have picked it up" (*The Economist*, 31 August, 1991).

presently not even willing to recoup the financial costs of building power plants by their pricing system, they are hardly likely to charge their citizens the environmental cost!

Perhaps this is being a little unfair to the EFOM research and one should look elsewhere for analysis of the market mechanisms and policy instruments that will promote the search for greater energy efficiency. In this respect the work of the OECD computable general equilibrium model is very relevant, and we turn to it now.

3.4 The OECD GREEN Model for Analysis of CO_2 Policies

The GREEN Model

One of the most ambitious approaches to CO_2 modelling is that taken by the OECD Economics and Statistics Department in developing the GREEN model (OECD, 1991b). This is a computable general equilibrium (CGE) model of similar type to the OECD's WALRAS model which is used in analysis of agricultural policies in the GATT talks (OECD, 1989). Since a separate presentation of the *GREEN* model and applications is given later in this volume, only some very brief points need be made in the present review of energy modelling applications.

Based on the Walrasian (or market clearing) tradition, CGE models describe the allocation of resources in a market economy as the result of the interaction of supply and demand, leading to equilibrium prices. Assuming that market forces will lead to equilibrium between supply and demand, the CGE model computes the market-clearing prices, and determines the allocation of resources and the distribution of incomes that result from this equilibrium. Hybrid CGE models can be specified where certain markets are in disequilibrium (e.g., the labour market) while others (e.g., the goods market) are in equilibrium. CGE models are typically rich in sectoral detail to a greater extent than even HERMES. This is because the requirement to estimate the model parameters econometrically from historical time-series constrains the HERMES-type model to a level of disaggregation for which data is readily available. CGE models, on the other hand, are "calibrated" in a more eclectic way. So, in terms of CGE sectoral detail, the sky is the limit! Of course, the larger a CGE model is, the more difficult it will be to solve, so there are pragmatic limits to its size.

CGE models are appropriate for the study of economies where the market mechanism - even if constrained by government intervention - still remains the dominant mode for allocating resources (Borges, 1986). In that situation, a CGE approach is required where the impact of policies is likely to be of economy-wide significance, cutting across many sectors and impacting on producers and consumers simultaneously, and where long-term impacts need to be investigated. In fact there are many similarities between a carefully specified neo-Keynesian macro-dynamic model like HERMES and a CGE model of equal sectoral disaggregation (Bradley and Whelan, 1991).

GREEN is a multi-sector, multi-region, dynamic CGE model for evaluating the costs of policies to reduce CO_2. All regions are linked with bilateral world trade matrices in a system which resembles a simplified version of the HERMES bilateral trade-flow model (a detailed description of the structure of GREEN is contained in Chapter 4). The carbon tax is introduced into GREEN as an excise tax, expressed as a fixed absolute amount of $US per tonne of emitted carbon and is applied at the level of primary fuel only. In each region the tax is computed as the equilibrium shadow price that would be paid for a additional tonne of CO_2 emissions when a given constraint on total emissions is imposed. However, GREEN also allows for the possibility that any global agreement to curb CO_2 emissions could include a provision allowing countries to trade rights to carbon emissions.

Finally, as with most CGE models, the key numerical coefficients in GREEN are not estimated econometrically, but are selected by the authors based on empirical evidence and on eclectic priors. Other coefficients are chosen so as to force the model to reproduce the historical data for some given year. Such an approach clearly calls for a more searching sensitivity analysis than would be necessary in an econometric model.

Using the GREEN Model

The OECD have used the GREEN model to analyse various scenarios of alternative international agreements (OECD, 1991a). The chosen policy instrument to achieve the emission reduction targets in all their scenarios involved the use of a carbon tax. The results from these scenarios are fully presented in Chapter 4. These results indicate that the level of carbon taxes required to meet the Toronto Agreement targets with full global cooperation, when averaged over all regions, is $215 per tonne of carbon (in 1985$). The tax varies between regions from a high in the Pacific to a low in China (see Table 4.4). Also, by the year 2020, household real income, averaged across all regions, is 2.2 per cent lower compared with the baseline, even when the tax revenues have been returned to consumers as cuts in marginal direct tax rates.

Specific curbs on CO_2 emissions can be regarded as initial endowments of emission rights. When a facility to trade in emission rights is included the GREEN model shows that these cuts are optimally distributed across regions given that a common equilibrium CO_2 tax is applied to all regions. The common tax amounts to $152 (in $1985) per tonne of carbon in 2020. The efficiency gains from allowing trade in emission rights are computed by comparing the magnitude of the change in household real income between the scenarios when emission trading is either prohibited and permitted. In terms of the cumulative effects over the period 1995-2020, the gains from trade are significantly positive for less developed regions with no affect for Europe and North America (see Chapter 4). The GREEN model shows that where only the OECD participates global emissions continue to grow after 2020. The major non-OECD countries must participate if the Toronto targets are to be met.

3.5 The OECD Comparative Study Of Global Models

In addition to developing and using its own tools of analysis, the OECD has taken on the role of surveying, reviewing and co-ordinating other empirical studies of GHG emissions (Hoeller *et al.* (1991); OECD, 1991c).[7]

Such reviews indicate the relative paucity of global models, even though the "Greenhouse Effect" has global implications. There is a clear trade-off between the regional and sectoral scope of the models, as evidenced by the large difference in industry detail between the global and single-country models examined.

The different models are found to answer different questions. For example the short-run macro-models are able to quantify short-run transitional or frictional costs such as additional expenditures on pollution control plus foregone output from existing capital that becomes unprofitable or has to be prematurely scrapped.[8] In addition, they permit analysis of labour market responses and macro responses to imbalances in prices, the public finances and trade. In the short run it is probably not critical that they are poor in modelling substitution possibilities as short-run substitution elasticities are typically low.

Long-run models, while incorporating elements of frictional costs, are better able to model longer term substitution possibilities and reallocation of resources in a realistic way. Modelling technical change and assessing the deadweight loss of taxation are important considerations and CGE and other dynamic optimising models provide the best tools.

The central features of the international CO_2 literature tend to mirror those already discussed above in the EC research, and include:

(a) The nature of the CO_2 reduction targets analysed, most of which are variants on the Toronto-type agreement.

(b) The policy mechanisms used, mostly focussing on taxes which are differentiated by the carbon content of the different types of fossil fuels.

(c) The effects on growth of CO_2 emission reductions vary widely. Most studies indicate long-run reductions in growth rates arising from large emission reductions of between close to zero and 0.3 per cent annually.

(d) There are significant variations in tax rates for the same amount of emission reduction among models. Marginal reduction costs rise with the amount of emission reduction. Tax rates of about $250 per tonne on carbon for large reductions imply a more than five-fold increase in the price of coal, a more than doubling of petrol prices, and a large increase in natural gas prices.

[7]It should be noted in passing that the only reference in the OECD survey (Hoeller *et al.*, 1991) to the energy modelling work of the Joule Programme is to the development of the MIDAS-HERMES linked system by Capros *et al.*, 1990. Given the sophistication of the HERMES energy modelling, it is somewhat disappointing that the HERMES model does not carry more *weight* on the world stage.

[8]It should be stressed that HERMES is not exactly your typical "short-run" macro model (in the OECD sense) but is specifically designed to have desirable medium-term properties and an energy sub-model. A five-year time horizon probably represents the valid extent of usefulness of a model like HERMES.

(e) Short-run sharp reduction in emissions will be costly because of high short-run adjustment costs and the absence of low-cost back-stop technologies, e.g. solar or wind energy. Those models which endogenise back-stop technologies (e.g., Manne and Richels, 1990) show lower long-run costs of emission reduction. If substitution possibilities continue to be limited, and cheap back-stop technologies are unavailable, reductions of CO_2 emissions will mainly occur via the costly route of policy induced reductions in energy use.

(f) The terms-of-trade effects and changes in trade patterns are large and appropriate trade policies are needed to equalise regional welfare losses.

In the Autumn of 1990 the OECD launched a model comparison exercise in an effort to attempt to standardise key model inputs and reduction target scenarios, so as to understand better the way in which the various models work and how differences arise in key results, i.e., on baseline emission paths, carbon taxes and economic costs. This is proceeding in parallel with the Energy Modelling Forum of Stanford University.

3.6 Lessons From Current Work On CO_2 Modelling

From our brief review of the CO_2 modelling literature, it is clear that the range of models in use within the EC Commission is deficient only in respect to the absence of any long-term global model of the OECD *GREEN* type. On the macroeconomic side, the Commission's HERMES model is state of the art but seems to lack a "presence" on the world stage.[9] The Commission's MIDAS and EFOM models represent the culmination of major research efforts but with the exception of the international recognition given to the work of the NTUA, this work was also not picked up in the OECD survey. Since the nature of the debate on the "Greenhouse Effect" will be dominated by scientific and technical analysis of the complex issues involved, it is vitally important to establish the credibility of the Commission's models and other scientific work both within the global economic and scientific community and to the public at large.

What do policy makers look for from models? In the case of CO_2 analysis, given the uncertainties surrounding the scientific evidence and future economic developments, models should be seen as providing a guide to policy makers in choosing among different policy options rather than as a precise quantification of economic costs. It makes sense for the EC to study CO_2 issues in a global context as well as in the context of the individual member states. Some tool is needed to do "big-picture" CO_2 work within the Commission of the same type as the OECD, but with the ability to identify separate member state issues in more detail than the OECD.

[9]For example, the OECD is clearly not aware of the power of HERMES for energy policy analysis. The long delay in publishing the HERMES book associated with the EC *1992* study has exacerbated the identity problem. A search of English language academic journals only produced the Belgian HERMES model (in the journal *Economic Modelling*).

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Chapter 4

THE ECONOMIC COSTS OF INTERNATIONAL AGREEMENTS TO REDUCE GLOBAL EMISSIONS OF CO_2

Jean-Marc Burniaux, John P. Martin, Giuseppe Nicoletti and Joaquim Oliveira Martins[1]

4.1 Introduction

In recent years there has been growing concern that human activities may be affecting the global climate through emissions of "greenhouse gases" (GHGs). The Intergovernmental Panel on Climate Change (IPCC) estimates that the average rate of increase of global mean temperature during the next century will be about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C), if no actions are taken to reduce GHG emissions. Such warming could have major impacts on economic activity and society. As a result, policy makers have begun to consider various ways of curbing emissions of GHGs and the likely costs and benefits of such actions.

There is a rapidly growing literature quantifying the economic costs of various policies to reduce GHG emissions (see Hoeller et al., 1991 for a survey of the literature). Such quantification should be world-wide, be able to take account of significant shifts in the patterns of production, consumption and trade and, because of the long-term nature of global warming, it should be based on a dynamic model.

The OECD Secretariat has developed a multi-region, multi-sector, dynamic applied general equilibrium (AGE) model to quantify the economic costs of policies to curb emissions of carbon dioxide (CO_2), the main greenhouse gas. The project is called the **G**ene**R**al **E**quilibrium **EN**vironmental model, hereafter referred to as GREEN. The purpose of this paper is to outline the main features of GREEN in a non-technical fashion and to present some simulation results of alternative international agreements to cut emissions. It must be stressed at the outset that these results are preliminary.[2]

[1]The authors are members of the Resource Allocation Division, Economics and Statistics Department, Organisation for Economic Co-operation and Development (OECD), Paris. This paper is an abridged version of Economic and Statistics Department Working Paper No. 103 which was published in June 1991. They would like to thank Laurent Moussiegt and Isabelle Wanner for statistical assistance, and Lyn Louichaoui for technical assistance. The views expressed in this paper are our own and cannot be held to represent the views of the OECD or its Member Governments.

[2]We are currently working to extend GREEN in a number of directions to make it more policy relevant. This will include extending the number of separate countries/regions to twelve, introducing back-stop technologies and incorporating existing energy taxes and subsidies.

The structure of the paper is as follows. Section 4.2 outlines the main features of GREEN in a non-technical fashion. This is followed by a brief discussion of fossil-fuel demands and emissions growth in the baseline scenario, in which it is assumed that no constraints are applied to emissions. Section 4.4 presents the simulation results for alternative international agreements under which the chosen policy instrument to restrict emissions is a carbon tax. The effect of extending the international agreement to allow for trade in emission rights is also analysed. The final section presents some conclusions.

4.2 Overview of the Main Features of GREEN

The key dimensions of GREEN are set out in Table 4.1. The present version of the model has a *medium-term* focus: it runs over a 35-year time horizon to 2020. A full description of the model's specification, data base and calibration/parametrisation is contained in Burniaux *et al.* (1991).

Table 4.1. *Key Dimensions of the GREEN Model*

PRODUCER SECTORS	CONSUMER SECTORS
(1) Agriculture	(1) Food, beverages and tobacco
(2) Coal mining	(2) Fuel and power
(3) Crude oil	(3) Transport and communication
(4) Natural gas	(4) Other goods and services
(5) Refined oil	
(6) Electricity, gas and water distribution	
(7) Energy-intensive industries	
(8) Other industries and services	
REGIONS	**PRIMARY FACTORS (a)**
(1) North America	(1) Labour [1]
(2) Europe (EC and EFTA)	(2) Sector-specific "old capital" [8]
(3) Pacific (Australia, Japan, New Zealand)	(3) "New" capital [1]
(4) Energy-exporting LDCs (b)	(4) Sector-specific fixed factors for each fuel [4]
(5) China	(5) Land in agriculture [1]
(6) Former Soviet Union	
(7) Rest of the World (RoW)	

Notes: (a) Figures in parentheses represent the number of each primary factor in each regional sub-model.
(b) This grouping includes the OPEC countries as well as other oil-exporting, gas-exporting and coal-exporting countries. For a full listing of the countries, see Table 4 in Burniaux *et al.* (1991).

GREEN consists of six detailed regional sub-models: three OECD regions - North America, Europe and the Pacific - and three non-OECD regions - the former Soviet Union, China and the energy-exporting LDCs (mainly OPEC). Because of the global nature of the GHG problem, specific attention was paid to modelling some key non-OECD regions. In that regard, it was deemed a high priority to model China and the former Soviet Union separately. It was also judged important to group together the major energy-exporting developing countries. Finally, the model contains a residual aggregate for the Rest of the World (RoW). RoW is not modelled with a detailed GE structure but instead is represented by a set of import and export equations which serve to ensure consistency in world trade flows.

In GREEN, saving decisions affect future economic outcomes through the accumulation of productive capital. Investment decisions are not modelled and investment is computed residually. In each region, the model is calibrated on exogenous growth rates of GDP and neutral technical progress in energy use. The current version is simulated over the period 1985-2020, using time intervals of five years. Given the recursive structure of the model, the evolution over time of the economy can be described as a sequence of single-period temporary equilibria. The main characteristics of these equilibria are outlined next.

A. Single-period equilibrium

Production

There are eight producing sectors in GREEN, chosen to highlight the relationships between resource depletion, energy production and use, and CO_2 emissions. The main focus is on the energy sector. Three sources of fossil-fuel energy - oil, natural gas and coal - and one source of non-fossil (so-called "carbon-free") energy - nuclear, solar and hydro power - are distinguished. The production side of each regional model describes the supply of fossil fuels and the use of fossil and non-fossil energy inputs in the productive process. Allowance is also made for shifts in the composition of production by treating agriculture as a separate sector, and by distinguishing between two other broad sectors, energy-intensive industries and other industries and services.

All sectors are assumed to operate under constant returns to scale and share a common production structure. The quantities of all inputs are chosen optimally by producers in order to minimise costs given the level of sectoral demand and relative after-tax prices. Simplifying assumptions on the available technology make it possible to separate the decisions of producers into several stages. The energy bundle is allocated among the alternative energy sources in the model, assuming a constant elasticity of substitution among them. This inter-energy substitution is a crucial factor in determining the level of CO_2 emissions.

Once the optimal combination of inputs is determined, sectoral output prices are calculated for each period assuming competitive supply (zero-profit) conditions in all markets except crude oil in the energy-exporting LDCs. The real world price of crude oil is exogenous. Since each sector supplies inputs to other sectors, output prices - which are the cost of inputs for other sectors - and the optimal combination of inputs are determined simultaneously in all sectors, conditional on the exogenous oil price.

Consumption

Consumer demand is split between four broad consumption aggregates (food and beverages, fuel and power, transport and communication, other goods and services) and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demands for the other four goods.[3]

Carbon tax

The carbon tax is expressed as a fixed absolute amount of US$ per tonne of carbon. In each region, it is computed as the equilibrium shadow price that would be paid for an additional tonne of CO_2 emissions when a given constraint on total emissions is imposed. The tax is fuel-specific i.e. it varies in proportion with the CO_2-emission coefficients of oil, coal and natural gas. It is applied at the level of consumers of primary fuels, thereby avoiding distortions between domestic and imported fuels; it is also applied prior to any indirect taxation included in the model.

Government

The government collects carbon taxes, income taxes and indirect taxes on intermediate inputs, outputs and consumer expenditures. Tax revenues depend on the level of economic activity. In addition, income-tax rates are adjusted to compensate for variations in the budget caused by changes in carbon tax revenues. Government expenditures are allocated among transfer and non-transfer expenditures. Both types of expenditures are exogenous in real terms, growing at the same rate as GDP.

Foreign trade

A set of bilateral trade matrices describes how price and quantity changes in each region affect world markets. Imports originating in different regions are treated as imperfect substitutes. In each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. This specification of imports - commonly referred to as the Armington specification - implies that each region faces downward-sloping demand curves for its exports.

The Armington specification is implemented for all goods except crude oil, which is assumed to be a homogeneous commodity.[4] The energy-exporting LDCs are assumed to fix the price in the world oil market and the other regions behave

[3]The demand system in GREEN is a version of the Extended Linear Expenditure System (ELES) which was first developed by Lluch (1973). The formulation of the ELES is based on an atemporal maximisation of a Stone-Geary utility function by treating saving as a good with zero *subsistence quantity* - see Howe (1975). This formulation assumes away any dependence of saving on the opportunity cost of current consumption (i.e. the rate of return on assets) by implicitly embodying the latter in the constant marginal propensity to consume.

[4]Natural gas and coal are assumed to be heterogeneous goods across regions due to transportation costs which are much higher than for oil.

as price-takers. Flows of oil between regions are the outcomes of the balance between domestic demand and supply of oil at given world prices, with the energy-exporting LDCs acting as a residual supplier.

Each region runs a current-account surplus (deficit). The net outflow (inflow) of capital is subtracted from (or added to) the domestic flow of saving. To satisfy the world current-account constraint, the counterpart of this net flow is reallocated exogenously among the other regions. No account is taken of international income flows associated with changes in stocks of net foreign assets.

Trade in emission rights

Any international agreement to curb CO_2 emissions could include a provision allowing countries to trade emission rights. In GREEN, countries are endowed with an initial allocation of emission rights, set arbitrarily equal to the upper bounds on emissions imposed in the no-trade in emissions case. A constraint on CO_2 emissions is imposed at the world level, a world price of emissions is determined as the equilibrium carbon tax associated with this constraint, and regions can trade emission rights freely at this price. Regions with a lower carbon tax in the no-trade case will want to sell permits, while those in the opposite situation will want to buy them. Trade in emission rights, therefore, gives rise to flows of income between regions which are taken into account in the current account constraint. It is assumed that these income flows accrue to the government.

Closure

In each period, gross investment equals net saving (the sum of saving by households, the net budget position of the government and foreign capital inflows). The government budget as a share of GDP is held constant at its benchmark-year value, while the current account is fixed in nominal terms.[5] Changes in the government budget induced by carbon taxation are assumed to be automatically compensated by changes in marginal income tax rates - the carbon tax is revenue-neutral. Since government and foreign trade imbalances are exogenous, this particular closure implies that investment is driven by saving. Alternative closure rules would almost certainly give different welfare outcomes.

B. Dynamics

The intertemporal dimension of GREEN is recursive. Agents base their decisions on static expectations about prices and quantities. There are two stocks: fossil-fuel resources and capital. A resource depletion sub-model is specified for oil and natural gas. Production depends upon the initial levels of proven and unproven (so-called "yet-to-find") reserves, the rate of reserve discovery and the rate of extraction. The sum of proven and unproven reserves is predetermined in each period. The rate of reserve discovery is the rate at which unproven reserves are converted into proven reserves. The rate of extraction is the rate at which proven reserves are converted into output. Whether output increases or decreases over time

[5]This assumption implies that current account / GDP ratios converge to zero in the long run.

depends on whether extracted resources are balanced by newly discovered reserves. The levels of unproven reserves of oil and gas are assumed to be sensitive to the prices of oil and gas.

In the aggregate, the current capital stock is equal to the depreciated stock inherited from the previous period plus gross investment. At the sectoral level, industries can disinvest faster than their (sector-specific) depreciation rates, when their demand for capital is less than their depreciated stock. The extent of disinvestment (sale of second-hand capital goods to other sectors) is determined by the ratio of the sector-specific rental of old capital to the economy-wide rental of new capital. In each period, the capital available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

In the baseline scenario, model dynamics are calibrated in each region on exogenous growth rates of GDP by imposing the assumption of a balanced growth path. This implies that the capital-labour ratio (in efficiency units) is held constant over time.[6] When alternative scenarios are simulated, the growth of capital is endogenously determined by the saving/investment relation.

C. The benchmark data sets

The "benchmark" year in GREEN is 1985, the year for which the latest input-output (I-O) tables are available for most OECD countries. Since I-O tables were not available for most non-OECD countries, a "minimum information" procedure was developed to estimate a consistent data set for these countries. This involved combining data from UN and IEA sources with coefficients from another country's I-O table.

I-O tables were available for China and the former Soviet Union. But there is an important caveat about these two I-O tables: they are based on domestic price structures which are very different from world prices. These price distortions are very large in the energy sector. As will be noted in the next section, they play an important role in accounting for some of the differences in model outcomes across regions.

Table 4.2 presents benchmark data on some key indicators which will prove useful in understanding the simulation results in the next section. The first indicator expresses CO_2 emissions relative to household real income (in 1985 U.S.$). China and the former Soviet Union are the most emission-inefficient regions on this indicator, while the Pacific is the most efficient region.

[6]This involves computing in each period a measure of Harrod-neutral technical progress in the capital / fixed factor bundle as a residual, given that the growth of the labour force (in efficiency units) is equal to the exogenous growth in GDP. This is a standard calibration procedure in dynamic AGE modelling - see Ballard *et al.* (1985).

Table 4.2: *Some Key Indicators in the Benchmark Data Sets by Country/Region. (1985)*

	North America	*Europe*	*Pacific*	*Energy Exporting LDCs*	*China*	*Former Soviet Union*	*Rest of World*	*Total*
1. Ratio of CO_2 emissions to household income (tonne C./10^6 1985$)								
	455	502	274	481	1,590	1,252		542
2. Share in total CO_2 emissions (%):								
Coal	34	28	34	20	87	38	70	42
Oil	47	59	57	67	11	33	22	42
Gas	19	13	9	14	1	29	8	16
3. Relative fossil fuel prices (1) (average price in North America = 100):								
Coal	34.7	62.5	102.7	31.9	21.3	25.5		51.6
Oil	147.5	175.0	170.7	107.1	159.3	24.7		117.7
Gas	95.0	130.1	132.8	117.2	109.6	17.4		80.1
Average	100.0	131.8	144.3	98.7	48.7	22.3		90.6

1. Defined as the unit value of one terajoule relative to the average unit value of fossil fuels in North America. Fossil fuel demands are converted into a common energy unit (1 terajoule = 1012 joules): this facilitates the conversion into tons of carbon emitted with the help of widely-used conversion factors: 1 terajoule of coal = 23.3 tons of carbon, 1 terajoule of oil = 19.2 tons of carbon and 1 terajoule of gas = 13.7 tons of carbon.

The second indicator measures fossil-fuel use. In China and RoW (mainly India and Eastern Europe), the vast bulk of CO_2 emissions arises from coal burning. Natural gas is a significant source of CO_2 emissions in the former Soviet Union, while oil is the main source in Europe, the Pacific and the energy-exporting LDCs. The third indicator measures relative prices of fossil fuels. Averaged over the six regions, coal and gas prices per terajoule are significantly lower than oil prices. Fossil fuel prices are particularly low in both China and the former Soviet Union: 46 and 75 per cent below the world average, respectively. All fossil fuel prices are very low in the former Soviet Union compared with world prices, whereas in China only coal has a very low price. Relative prices of fossil fuels are high in Europe and especially in the Pacific, where they are 60 per cent higher than the world average.

D. Selection of exogenous parameters

Values of certain exogenous parameters must be such that the benchmark data set is an equilibrium solution to the model. A literature search was undertaken to find "plausible" values for these parameters. Particular attention was paid to estimates of inter-energy elasticities of substitution, autonomous rates of energy efficiency improvement, and the foreign trade elasticities. The results of this literature search are described in detail in Burniaux et al. (1991).

Identical values for substitution elasticities in production and foreign trade are used for all regions. This is not very realistic, but the literature review provided little useful guidance on country-specific values. In line with the typical finding in the econometric literature, income elasticities of consumer demand are set at higher values in the non-OECD regions than in the OECD regions. There is much uncertainty about plausible values of autonomous rates of energy efficiency improvement. We have chosen to follow the conventional wisdom in energy forecasting that the energy/output ratio will decline by 1 per cent a year in all regions.

The production paths for oil and natural gas in most regions were calibrated to replicate projections for the year 2005 coming from the IEA's model of world energy markets. The sole exceptions were the former Soviet Union and China; the IEA model does not have gas projections for these countries. Production of oil and gas in both countries was calibrated on the projections for the year 2020 from the Edmonds and Reilly model.[7]

Table 4.3: *Assumptions for the Exogenous Variables in the GREEN Baseline Scenario.*

(a) GDP growth rate

Period	*North America*	*Europe*	*Pacific*	*Energy Exporting LDCs*	*China*	*Former Soviet Union*	*RoW*	*Total*
1990-2000	2.5	2.1	3.6	3.7	4.5	2.5	3.8	2.9
2000-2020	2.0	1.6	2.6	3.3	4.0	2.0	3.3	2.4

(b) World oil price

The world oil price fell from $27.6 per barrel in 1985 to $22 per barrel in 1990. Thereafter, it is assumed to increase by $6.50 per barrel in each decade until 2020.

4.3 Baseline Path of CO_2 Emissions

Deriving a plausible baseline path, i.e., the path that CO_2 emissions would be expected to take in the absence of policy actions to curb their growth, is a key element in estimating the costs of any such interventions. Once the baseline has

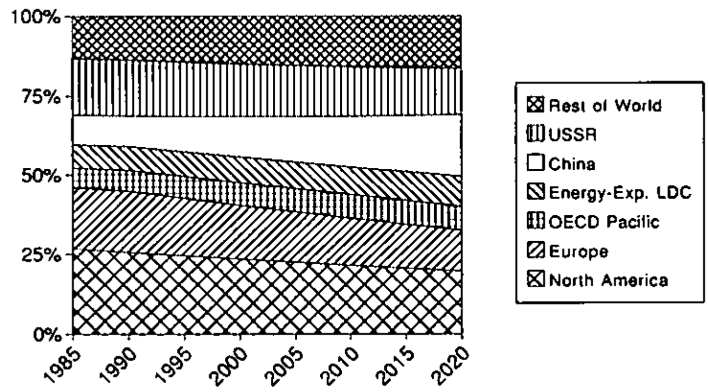
[7]The original version of the model is documented in Edmonds and Reilly (1985). For recent application of the model, see Edmonds and Barns (1990).

been established, it is possible to answer the following kind of "what if" question: "What would be the impacts on both OECD and non-OECD countries if they, individually or jointly, took actions to curb the growth of CO_2 emissions?"

The assumptions about both GDP growth rates and the world oil price underlying the baseline scenario are taken from the Stanford-based Energy Modelling Forum Study No. 12 (EMF12) entitled "Global Climate Change: Energy Sector Impacts of Greenhouse Gas Emission Control Strategies" (Table 4.3). The GDP growth rates in these projections are assumed to decline slowly after the year 2000 in all regions due to structural change and slower population growth.

Baseline world CO_2 emissions are projected to grow at an annual average rate of almost 2 per cent a year: the level of emissions increases from 5.2 billion tons in 1985 to almost 10 billion tons in 2020. The share of the OECD countries in global emissions declines from 52 per cent in 1985 to 40 per cent in 2020 (Figure 4.1), while China's share increases from 9 per cent in 1985 to 19 per cent in 2020. The shares of the former Soviet Union and RoW are very stable over the whole period.[8]

Figure 4.1
Regional Shares of Global CO_2 Emissions in the Baseline Scenario



[8]RoW has no general equilibrium structure in GREEN but it does produce CO_2 emissions. These arise as a result of the assumption that the level of emissions is proportional to GDP, adjusted by the exogenous increase of end-use energy efficiency:

$$Em_t^{RoW} = \frac{\prod_{t=1}^{n}(1+g_t)^t}{\prod_{t=1}^{n}(1+a_t)^t} \cdot Em_0$$

where Em_0 = initial level of CO_2 emissions, g = growth rate of GDP, and a = autonomous rate of energy efficiency.

Figure 4.2
CO_2 Emission Shares by Fossil Fuel Source
in the Baseline Scenario

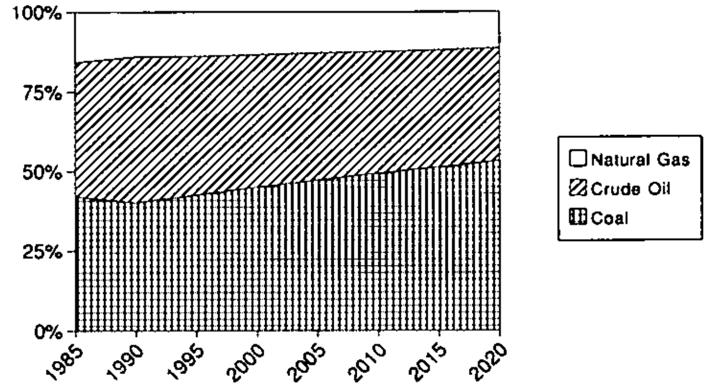


Figure 4.2 shows the contributions of the three fossil fuels to total world emissions. Emissions from coal increase from 42 per cent of total emissions in 1985 to 53 per cent in 2020, partly in response to shifts in relative prices: real oil prices grow much faster than real coal or gas prices after the year 2000. The major reason for the shift to coal is above-average growth in China, the main coal consumer with the lowest coal price.

4.4 Curbing CO_2 Emissions: Three Alternative International Agreements
(A). A Toronto-type agreement

Suppose that a global agreement was reached under which (i) CO_2 emissions in the OECD regions and in the former Soviet Union would be restricted to 80 per cent of their 1990 levels by 2010, and stabilised thereafter; and (ii) emissions in the energy-exporting LDCs and China would be restricted to be 50 per cent higher than their 1990 levels by 2010, and stabilised thereafter. What would such an agreement imply for carbon taxes and economic welfare?

Carbon tax

The levels of carbon taxes required to meet these targets are given in Table 4.4. Since the baseline projects a continued growth in CO_2 emissions in all regions, the carbon tax rises steadily over the period in all regions. By 2020, the tax, averaged over all six regions, is \$215 per tonne of carbon (the equivalent average for the OECD area is \$308) - all taxes are expressed in 1985\$. The level of the tax varies widely across regions, from a low of over \$60 in China to a high of over \$950 in the Pacific. There are several reasons for the high tax in the Pacific. In the baseline, CO_2 emissions in the Pacific grow faster than in the other OECD regions. The

Pacific also has the highest relative energy prices, particularly for coal (see Table 4.2), and domestic demand for coal is almost wiped out as a result of the imposition of the carbon tax - both factors serve to push the carbon tax into a region of sharply diminishing returns.[9] Finally, the Pacific is the most CO_2-efficient region. It, therefore, requires a much larger carbon tax than the other OECD regions to satisfy a uniform percentage cut in emissions.

Table 4.4. *Carbon Taxes by Region Under a Toronto-Type Agreement (1985 $/Tonne Carbon)*

	North America	*Europe*	*Pacific*	*Energy Exporting LDCs*	*China*	*Former Soviet Union*	*Total (1)*
1995	3	7	41	7	5	5	9
2000	14	16	104	15	11	12	21
2010	139	168	549	24	23	69	123
2020	209	213	955	209	63	101	215

1. Weighted average of the six regions where the weights are the share of each region in total CO_2 emissions.

North America and the former Soviet Union have similar carbon taxes in the 1990s despite the fact that domestic fossil fuel prices in the former Soviet Union are on average only one-fifth of the North American level. This follows from the fact that domestic energy demand in the former Soviet Union relies much more on natural gas - which has a lower carbon content than either coal or oil - than the other regions (see Table 4.2). The carbon tax rises faster after the year 2000 in North America than in the former Soviet Union as the demand for coal in the former region dries up.

Finally, it must be emphasised that the levels of the carbon tax are likely to be very sensitive to changes in model specification. For instance, the version of GREEN used to produce these results contains no backstop technologies - new energy sources which become profitable in the future when fossil-fuel prices are sufficiently high. Simulations with the Global 2100 model of Manne and Richels (1992) show that the time profile and levels of the carbon tax across regions are sensitive to the introduction of such technologies.

[9] Bearing in mind that the tax is specified as an absolute $ amount per tonne of carbon, a given relative energy price increase can be achieved by a lower carbon tax under the following conditions: (1) when fossil fuel prices are initially lower relative to world prices (a 1$ carbon tax has a larger impact in terms of relative price changes); and (2) when coal accounts for a large share of total energy demand, given that coal prices are lower than oil and gas prices in almost every region (see Table 4.2) and coal has a larger carbon content than either oil or gas. In addition, the carbon tax exhibits diminishing returns in terms of curbing emissions when coal use is eliminated and energy demand switches to more expensive fuels with lower carbon content.

Effects on real income, absorption and GDP

Meeting these emission targets via a carbon tax gives rise to costs, in terms of lower welfare and GDP. But some countries could conceivably benefit from a carbon tax via terms-of-trade gains. Estimates of the real income and GDP effects under this scenario are reported in Table 4.5. Two indicators are reported: (i) a measure of economic welfare, the change in household real income - the so-called "Hicksian equivalent variation", and (ii) real GDP.

The typical pattern across regions is for welfare losses to increase over time in line with the carbon tax. By the year 2020, household real income, averaged across all regions, is 2.2 per cent lower compared with the baseline.[10] The estimated costs are less than 1 per cent in North America, Europe and the former Soviet Union. The largest real income loss is recorded by the energy-exporting LDCs: by the year 2020 real income is 7.5 per cent lower. Table 4.5 also reports cumulated losses as shares of cumulated real income over the period 1995-2020: averaged over the six regions, real income is 1 per cent lower.

Real GDP falls compared with the baseline as the deadweight losses from the carbon tax lead to lower capital accumulation over time via the saving/investment relationship. Averaged across all regions, real GDP is almost 2 per cent lower in 2020; the largest losses are in the energy-exporting LDCs, the Pacific and the former Soviet Union.

Terms of trade

Levying a carbon tax will affect the terms of trade differently, depending on whether the region in question is an energy importer or an energy exporter, and this, in turn, will have an effect on welfare. Table 4.6 summarises the main mechanisms at work in these two types of region. The carbon tax cuts the demand for imported fossil fuels in energy-importing regions, thereby producing an energy trade surplus. Given the closure rule in GREEN, this has to be balanced by a corresponding trade deficit on non-energy goods and services. This is achieved by a rise in relative export prices (an improvement in the terms of trade). As a result, international markets for fossil fuels contract and energy-exporting regions suffer a terms-of-trade loss. The carbon tax also affects the competitiveness of exports of non-energy goods and services in both regions: their export price will increase in line with their energy content, thereby tending to improve the terms of trade.

[10]These deadweight losses are overstated for two reasons. First, the carbon tax is a *corrective* tax, i.e. it aims to raise the price of fossil fuels to reflect more adequately their social cost. Second, the revenues raised by the carbon tax are assumed to be returned to consumers in GREEN via a reduction in marginal income tax rates. Cutting other distortionary taxes should give rise to welfare gains but there is no mechanism in the present version of the model for this to occur.

Table 4.5. *Effects of the Carbon Tax on Real Income and GDP.*

Percentage changes relative to the baseline

Year	*North America* Household Real Income (1)	*North America* Real GDP	*Europe* Household Real Income (1)	*Europe* Real GDP	*Pacific* Household Real Income (1)	*Pacific* Real GDP
2000	-0.0	-0.0	0.0	-0.0	0.1	-0.3
2010	-0.3	-0.5	-0.5	-0.5	-1.0	-2.0
2020	-0.8	-0.8	-0.9	-0.7	-2.4	-3.7
Cumulated effect over the period 1995-2020 (2)	-0.3	-0.4	-0.4	-0.4	-1.1	-2.0

Year	*Energy Exporting LDCs* Household Real Income (1)	*Energy Exporting LDCs* Real GDP	*China* Household Real Income (1)	*China* Real GDP	*Former Soviet Union* Household Real Income (1)	*Former Soviet Union* Real GDP
2000	-1.1	-0.7	-0.3	-0.3	0.4	-0.1
2010	-4.4	-2.2	-1.1	-0.6	0.4	-1.1
2020	-7.5	-3.6	-2.3	-1.5	-0.6	-2.2
Cumulated effect over the period 1995-2020 (2)	-4.4	-2.1	-1.3	-0.8	0.1	-1.1

Year	*Total* Household Real Income (1)	*Total* Real GDP
2000	-0.1	-0.2
2010	-1.0	-1.0
2020	-2.2	-1.8
Cumulated effect over the period 1995-2020 (2)	-1.0	-0.9

1. Hicksian equivalent variation, i.e. the change in income a consumer would need before the imposition of a carbon tax to allow him to reach the welfare level he actually achieves after the change.
2. The sum of the annual gains and losses relative to the sum of annual real income and GDP, respectively.

Energy-importing regions are, therefore, likely to experience a terms-of-trade gain from a carbon tax whereas the effect is ambiguous in energy-exporting regions. The terms of trade could improve in those energy-exporting regions where the trade balance relies less on energy exports - such as the former Soviet Union.

Table 4.6: *Effects of a Carbon Tax on the Real Exchange Rate and Terms of Trade in Energy-Importing and Energy-Exporting Regions*

Effects of the Carbon Tax on:	*Energy-Importing Regions*	*Energy-Exporting Regions*
Energy trade:	(1) cuts in energy imports	(2) cuts in energy exports
	+	-
Non-energy trade:	(3) cuts in exports of non-energy goods and services	
	+	+
Total effect	+	?

The simulated outcomes for the terms of trade under a Toronto-type agreement generally confirm these expectations:

(Annual average changes compared with baseline)

	1985-2010	2010-2020
North America	0.1	0.9
Europe	1.1	2.7
Pacific	2.6	7.2
Energy-exporting LDCs	-2.3	-6.5
China	-1.5	-3.9
The former Soviet Union	1.6	4.8

The terms of trade improve in the OECD regions and in the former Soviet Union in response to the carbon tax, leading to gains in household real income which tend to offset the deadweight losses arising from the tax. Indeed, the terms-of-trade gains in the former Soviet Union outweigh the deadweight losses until after the year 2010. The former Soviet Union's terms of trade benefit from the relative price increase of its non-energy exports; it is the only region which experiences a rising share of fossil-fuel exports in total exports after the imposition of a carbon tax - the share rises by 26 per cent compared with baseline.

The energy-exporting LDCs experience a large terms-of-trade loss. China also experiences a terms-of-trade loss, mainly from shifts in the pattern of energy trade. On the export side, the fall in price and quantity of its coal exports leads to a decline in the relative export price of non-energy goods and services. There is also a sharp increase of crude oil imports as a result of inter-energy substitution away from coal towards oil; the existence of binding supply constraints for crude oil means that the additional demand for oil has to be met entirely by imports.

(B). A Toronto-type agreement with trade in emission rights

Specific curbs on CO_2 emissions can be considered as initial endowments of emission rights. We now report the results of a Toronto-type agreement which imposes the same global constraint on CO_2 emissions as the first scenario, but allows for trade in emission rights. Under this scenario, emission cuts are optimally distributed across regions given that a common equilibrium tax is applied in all regions (excluding RoW).

The common tax amounts to \$152 (in 1985\$) per tonne of carbon in 2020, implying that trade in emission rights serves to lower the tax in the OECD regions and the energy-exporting LDCs compared with a no-trade agreement. The tax triples in China and increases by 50 per cent in the former Soviet Union. The optimal allocation of emission cuts implies that the OECD regions and the energy-exporting LDCs want to buy emission rights from China and the former Soviet Union. By the year 2020, 8 per cent of annual global CO_2 emissions are traded.

Allowing for trade in emission rights permits the world to cut coal emissions even more than under the first Toronto-type agreement. With the burden of adjustment to the CO_2 constraint shifted more from oil and gas towards coal under this scenario, oil exports of the energy-exporting LDCs are less affected than in the no-trade case: oil production falls by less than 10 per cent in 2020 compared with a fall of over 17 per cent in the no-trade scenario. China sells emission rights to the OECD regions, mainly to the Pacific, and uses the resulting revenues to buy more oil imports from the energy-exporting LDCs. China earns \$62 billion (in 1985\$) from selling emission rights to the OECD regions - these revenues amount to 5 per cent of household real income in 2020. In return, it has to cut its yearly emissions by over 70 per cent below baseline.

The welfare gains from trading emission rights are expected to be important in China, the Pacific, the former Soviet Union and the energy-exporting LDCs. There should only be marginal effects in the other regions since none is a major trader in the market for emission rights. The efficiency gains from allowing for trade in emission rights are computed by comparing the magnitude of the change in household real income under the two scenarios. In terms of the cumulated effects over the period 1995-2020, the gains from trade are:

(Percentage changes relative to baseline)

North America	Europe	Pacific	Energy Exporting LDCs	China	Former Soviet Union	Total
+0.0	+0.0	+0.4	+2.0	+3.0	+0.6	+0.6

China, the energy exporting LDCs, the former Soviet Union and the Pacific are the main winners from allowing trade in emission rights. All four regions still record real income losses from meeting the CO_2 constraint, but in each case the losses are smaller when the global agreement contains a provision for trade in emission rights. The gains from trading emission rights are negligible for North America and Europe.

C. Curbing CO_2 emissions in industrial economies alone

Suppose that a Toronto-type agreement was adopted only by the industrialised economies, i.e. the OECD regions and the former Soviet Union. Global CO_2 emissions in 2020 would be cut by 23 per cent relative to baseline compared with a cut of 37 per cent in the global agreement. In addition, global CO_2 emissions would continue to grow at an annual rate of 1.6 per cent after 2010. This shows that any agreement which aims to curb CO_2 emissions at the global level must involve the major non-OECD countries if it is to be effective.

Levels of the carbon tax and the magnitude of the real income losses in the OECD regions and the former Soviet Union are virtually unchanged compared with the global scenario. The non-participants - the energy-exporting LDCs and China - do suffer losses, however, from the actions taken by the industrialised economies. For example, by the year 2020 their losses are:

(Percentage changes compared with baseline)

	Household Real Income	Real Domestic Absorption	Real GDP
Energy-exporting LDCs	-6.0	-4.9	-3.0
China	-0.6	-0.3	-0.2

China's welfare loss is small compared with its loss of over 2 per cent under the global scenario. But the losses to the energy-exporting LDCs are almost as high as under the global agreement, implying that the main source of welfare losses in this region arises as a result of carbon taxes being applied in the industrialised economies.

A variant of this simulation was also run in which the industrialised economies agreed to achieve the same reduction in global emissions as under a Toronto-type agreement. In order to achieve this target, the OECD regions and the former Soviet Union have to reduce their emissions in 2020 by two-thirds compared with the baseline level. This requires enormous carbon taxes: the average tax in the OECD area in 2020 would be $2,200 per tonne of carbon and over $500 in the former Soviet Union.

Carbon taxes on this scale lead to very large welfare losses: by 2020, real household income is 7 per cent below baseline in the OECD area and 4 1/4 per cent lower in the former Soviet Union. Once again, the energy-exporting LDCs are a major loser from the imposition of carbon taxes by the industrialised economies: their welfare loss is almost 10 per cent.

4.5 Conclusions

This paper presents the results of three scenarios of alternative international agreements. In the first scenario of a so-called "Toronto-type agreement", the industrialised countries - the OECD countries and the former Soviet Union - cut their emissions by 20 per cent below their 1990 levels by the year 2010, and stabilise them thereafter. A less stringent constraint is applied in China and the energy-exporting LDCs. The second scenario extends this global agreement to include a provision for trade in emission rights. In the third scenario, only the industrialised countries curb emissions. The chosen policy instrument to achieve the emission reduction targets in all three scenarios is a "carbon tax" - a set of taxes levied on fossil-fuel use in proportion to the carbon content of the fuels.

Under the first scenario, the level of the carbon tax in the year 2020 averages $215 per tonne of carbon (in 1985 prices and exchange rates) over all six regions. The equivalent OECD average tax is over $300; this corresponds to a tax of $36 per barrel of oil. The tax varies widely across regions, from a low of over $60 per tonne of carbon in China in 2020 to a high of over $950 in the Pacific region.

The costs, averaged over all six regions, of meeting these emission reduction targets, in terms of lower household real income (a measure of economic welfare) and real GDP, are estimated at $2^1/_4$ and $1^3/_4$ per cent, respectively, in the year 2020. The welfare costs are less than 1 per cent for North America and Europe, but are much larger - of the order of $7^1/_2$ per cent - for the energy-exporting LDCs and almost $2^1/_2$ per cent for the Pacific and China.

The regional spread of carbon taxes suggests that any international agreement which sets uniform targets should also include a provision allowing participating countries to trade emission rights. In the second scenario, all countries are assumed to have an initial endowment of emission rights. As a result of trading these rights, household real income, averaged across the six regions, would fall by only 1 per cent. The main beneficiaries from this trading would be the non-OECD regions, especially China and the energy-exporting LDCs, with lesser gains for the former Soviet Union and the Pacific. Allowing for trade in emission rights enables the world to cut the demand for coal more drastically, coal being the "dirtiest" fossil fuel in terms of carbon content. In consequence, China would be required to cut its CO_2 emissions more drastically than under the first scenario. In return for this, it would sell emission rights to OECD regions, mainly the Pacific, and derive substantial revenues - over $60 billion in 2020 (in 1985$) - from such trade. As a result, China would experience a welfare gain of 2.4 per cent in 2020 compared with a loss of $2^1/_2$ per cent in the no-trade case. The OECD regions consume more oil than they would have in the no-trade case, to the benefit of the energy-exporting LDCs.

If the industrial countries were to take action to curb emissions on their own, the costs to their economies would be virtually unchanged from what it would have been under a global agreement. But global CO_2 emissions would continue to grow at around $1^1/_2$ per cent a year and the non-participating regions, notably the energy-exporting LDCs, would suffer losses due to the carbon taxes in the industrialised countries.

This suggests that any international agreement will have to include many non-OECD countries, especially large CO_2 emitters like China, if it is to be successful in curbing global emissions. But since many of these countries could expect to suffer non-negligible losses from participating in any such agreement, there would need to be incentives to encourage them to adhere to it.

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Chapter 5

THE MACROECONOMIC IMPLICATIONS FOR IRELAND

John Fitz Gerald and Daniel McCoy

5.1 Introduction[1]

Environmental concerns have emerged at the centre of the international political agenda during the last decade. The possible consequences of the "Greenhouse Effect" including global warming, rising sea-levels and climatic changes have received a media prominence matched by few other global issues. As outlined in the preface to this policy paper, the European Commission in October 1991 announced a series of proposed policy changes, including a new carbon tax, which were aimed at limiting carbon dioxide emissions within the EC over the next decade. This chapter examines the macroeconomic implications for Ireland of the proposed tax.

In Chapter 2 Scott has discussed how taxes are a more suitable instrument than quotas for controlling carbon dioxide emissions due to their greater economic efficiency. While, like most taxes, the carbon tax would involve deadweight losses, the revenues raised by such a tax could provide society with a "double dividend" Pearce (1991). This double dividend stems from the improvement in the environment through reducing the likelihood of global warming along with the ability to use the revenue collected to reduce other distorting taxes on incomes, expenditure, or corporations. Whether or not the change in structure of taxation implied by these new taxes improves the efficiency of the tax system will depend on the precise characteristics of the tax system in each member of the EC. This paper examines the implications for Ireland of such a change in the structure of domestic taxation.

Underlying this paper is the question of how the environmental objective of reducing carbon dioxide emissions can be achieved with minimum dislocation to the economy. The issue of what should be the appropriate long-term objective in terms of restricting emissions of GHGs is left to other more qualified fora.

Section 5.2 of this chapter gives a brief description of the pattern of energy use and carbon dioxide emissions in Ireland. The methodology used in the chapter is outlined in Section 5.3. The results of detailed simulations which examine the likely impact on the Irish economy of a unilateral imposition of a carbon tax are

[1]The authors would like to thank their colleagues Dr. John Bradley and Ms. Sue Scott for their helpful comments on earlier drafts of the paper. The results in this paper draw heavily on their earlier work in related areas.

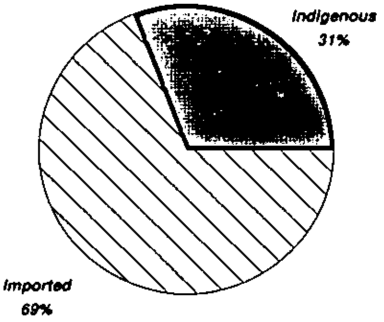
set out in Section 5.4. Section 5.5 considers how our results might be changed by assuming that the tax is imposed throughout the EC. Our conclusions are detailed in Section 5.6.

5.2 Energy Use and Carbon Dioxide Emissions in Ireland

Historically because of the absence of a major domestic source of energy and the relatively high price of energy in Ireland the industries which have developed and prospered have been those with relatively low energy intensity. Major industrial sectors which are intensive users of energy, such as steel, non-ferrous metals, cement and glass, are under-represented in the Irish economy. This pattern of development is reflected in the fact that expenditure on fuel and power accounted for only 1.9 per cent of the total turnover of manufacturing industries in 1988 CSO (1991).

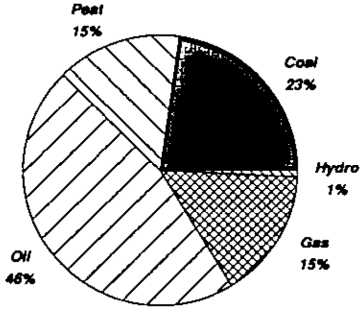
Ireland's indigenous energy resources are limited. In 1990 Ireland's imports of energy were nearly 2.3 times the volume of energy available from indigenous sources (Figure 5.1). As a result, indigenous sources account for only 35 per cent of Ireland's total energy requirements in 1988 compared to the EC average of 53.8 per cent.

Figure 5.1
Source of Energy in Ireland, 1990



Department of Energy

Figure 5.2
Shares of Total Primary Energy, 1990



Department of Energy

For the rest of the 1990s Ireland's dependence on imports is likely to increase. Indigenous known reserves of natural gas will be depleted by the end of the decade to be replaced by imported gas. This imported gas will come through a gas interconnector with the UK expected to be in operation in 1994. The opportunities for further use of hydro power by the electricity generation industry seems limited. The use of peat in electricity generation is very inefficient and it is also the fuel with the highest carbon content per unit of energy (see Table 5.1). Imported oil and coal form the largest shares of Ireland's energy requirements compared to indigenous peat and natural gas.

Ireland's consumption of energy per capita in 1988 was 2.667 TOEs compared to the EC average of 3.319 TOEs. This is not altogether surprising given that Ireland's standard of living is below the average for the EC as a whole. However, when consumption is related to GDP Ireland is seen to be a somewhat more intensive

Table 5.1: *Tonnes of CO_2 per Tonne of Oil Equivalent*

Peat	4.34
Coal	3.70
Oil	3.01
Gas	2.07

user of energy: in 1989 Ireland consumed 0.39 TOE per thousand pounds of GDP compared to the EC average of 0.32. The energy intensity of the economy has declined from 0.49 in 1973, before the first oil crisis, to 0.39 TOE per thousand pounds of GDP in 1989 (Cash, 1990).

Ireland's emissions of CO_2 have grown broadly in line with its economic development from the 1960s. The growth in Ireland's CO_2 emissions from fossil fuels in each decade has been much higher than the EC average over the period (Table 5.2).

Table 5.2: *Percentage Growth in CO_2 Emissions from Fossil Fuels For Each Decade from 1960-2000*

	1960s	*1970s*	*1980s*	*1990s**
Ireland	84.5%	39.4%	26.4%	24%
EC Average	48.5%	11.8%	-7.7%	23%

* Forecast

The distribution of energy consumption by fuel in Ireland is shown in Table 5.3. For most of the fuel types the structure of Irish energy supply is broadly comparable to the EC average. However, the striking difference between the figures for Ireland and those for the EC is that Ireland draws 14.7 per cent of its energy from peat, which emits a disproportionate amount of CO_2 per unit of energy, while the EC draws 14.3 per cent of its energy from CO_2 emission free nuclear generators.

Because of Ireland's dependence for energy on fossil fuels, especially solid fuels with high carbon contents, emissions of CO_2 are quite high. Whereas Irish consumption of energy per capita is below the EC average, CO_2 emissions per capita in 1989 were 30.4 tonnes compared to an EC average figure of 29.7 tonnes. The contrast is even more striking when expressed in terms of units of GDP: in 1989 Ireland emitted 4.6 tonnes per thousand pounds of GDP compared to 3.9 for the EC as a whole. However, in spite of the greater carbon intensity of the economy, Ireland's emissions of CO_2 account for only 0.1 per cent of the world total CO_2 emission.

Table 5.3: *Energy Consumption by Fuel, 1989 (%)*

	Coal	*Peat*	*Oil*	*Gas*	*Nuclear*	*Other*	*Total*
Ireland	25.3	14.7	43.0	16.4	0	0.6	100
EC	21.0	0	44.8	18.3	14.3	1.6	100

Ireland's CO_2 emissions for 1990, the target year for stabilisation of emissions, are estimated to be approximately 31 million tonnes. The contribution by fuel type and by sector to these CO_2 emissions is shown in Figures 5.3 and 5.4 respectively. Oil at 44 per cent accounts for the largest share of CO_2 emissions among the fuels by nature of the fact that it also accounts for nearly 46 per cent of national energy requirements. Coal and peat account for a larger share of CO_2 emissions than would be suggested by their share in total energy supply because of their above average carbon content per unit of energy. The opposite is the case for natural gas which has a lower carbon content per unit of energy than other fossil fuels.

Figure 5.3
CO_2 Emissions by Fuel 1990

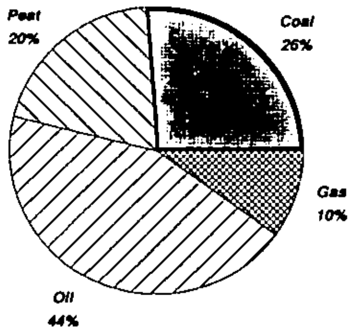
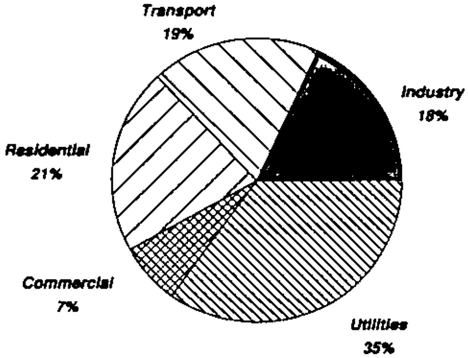


Figure 5.4
CO_2 Emissions by Sector 1990



The benchmark forecast for the Irish economy's energy requirements over the period 1990-2000 is presented in Table 5.4. The growth in total energy demand in the economy over the benchmark period is forecast to be 30.8 per cent. The forecast growth in CO_2 emissions over the period 1990-2000 is 24.4 per cent. This growth is less than that forecast for energy demand reflecting the change in the mix of fuel used away from high carbon content per unit of energy fuels like peat, towards greater use of natural gas.

Table 5.4: *Benchmark Energy Use and CO_2 Emissions 1990-2000*

Sector	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Total Energy (MTOE)	9.7	9.9	10.2	10.5	10.8	11.1	11.4	11.7	12.0	12.3	12.7
Total CO_2 (M. Tonnes)	31.1	31.9	32.7	32.9	33.7	34.6	34.6	35.6	36.6	37.6	38.6

5.3 Modelling Energy Demand in Ireland

The quantification of the macroeconomic effects for Ireland of the proposed carbon tax can only be undertaken within the framework of a macroeconomic model. The most suitable model for this task is the ESRI Medium Term Model (HERMES). As outlined in Chapter 3 by Bradley, the ESRI's model is part of an EC-wide set of models which were developed especially to deal with energy policy issues in the early 1980s.

In the Medium Term Model (MTM) energy enters directly into the three manufacturing subsectors[2] and into the utilities sector. The building sub-sector and the agriculture sector use an aggregate "Energy + Materials" factor input. The marketed services and the non-marketed services sectors are modelled in a value-added (capital + labour) framework so energy is not explicitly included as an input into these sectors. Household consumption of energy is not treated explicitly in the model.

The rather aggregate treatment of energy in the standard MTM model has been supplemented by developing a special energy sub-model which incorporates the main flows in the energy balance sheets produced by the Department of Energy. While this energy sub-model does not attempt to explain how fuel mix is likely to change in the face of major changes in relative prices, it does allow a more precise estimation of the impact of the proposed carbon taxes on prices generally in the economy. Through the MTM model the macroeconomic effects of the price changes can be examined.

The sectoral breakdown used in the sub-model is: industry, transport, residential, commercial, and utilities. The demand for energy from each of the sectors, other than utilities, excludes electricity so that the demand from the utilities sector (electricity, gas and water) is treated as a final demand.

There is considerable uncertainty as to the likely response of energy use to changes in prices or demand, measured as elasticities, for these sectors in Ireland. In the short term the possibilities of substituting other factor inputs for energy are limited. Over a longer period there is greater possibility of energy saving and the substitution of other factors for energy in response to the higher energy price generated by the tax. In the energy sub-model the estimated elasticities probably underestimate the long-run possibilities of energy saving. However, they are considered realistic in an exercise, such as this, which examines likely developments over a five to ten year time horizon.

[2]The manufacturing sector is disaggregated into "High Technology", "Food" and "Traditional" sub-sectors.

The elasticity of demand for energy in the industrial sector is estimated at around -0.3, i.e. a one per cent rise in the price of energy will lead to a 0.3 per cent fall in energy demand. A similar elasticity has been imposed for household demand for energy (excluding electricity). However, these elasticities, even where estimated from historical data, are subject to quite a wide margin of error.

While the MTM model, with its allied energy sub-model, can examine how energy demand may change in the face of changing prices, the current version does not model the demand for individual fuels. This means that the results, discussed below, will tend to underestimate the possible impact of carbon taxes on CO_2 emissions and, possibly, overestimate the adverse consequences of the tax change. If the mix of fuels consumed varies in response to changes in relative prices, it is certain that there will be some additional switch from high carbon fuels to low carbon fuels, such as natural gas, when a carbon tax is imposed, further reducing CO_2 emissions.

The MTM model can examine the impact of a unilateral imposition of a carbon tax on the Irish economy. However, if, as is proposed by the EC Commission, the tax is imposed throughout the EC, the channels through which the policy change will affect the Irish economy are more complex. The price level in other EC countries will change and this will affect the rate of growth throughout the region. Preliminary results for other EC countries are discussed by Bradley in Chapter 3.

The first issue to be considered in modelling the impact of the carbon tax is to what extent the incidence of the tax will fall on the domestic economy and to what extent it will be passed back to foreign energy producers. The evidence suggests that in the medium term the elasticity of demand for energy is low while the elasticity of supply faced by Ireland is high. As a result most of the incidence of the tax, if imposed unilaterally, will fall on domestic users.

If the tax is imposed on an EC wide basis the supply curve faced by the EC is somewhat less elastic than that faced by Ireland on its own so that an EC tax would see somewhat more of the incidence falling on energy producers. However, even in this case, because of the low elasticity of demand for energy in the EC in the medium term, the bulk of the incidence would still fall on consumers in the EC. In so far as prices of energy received by producers fell due to the tax, the benefits of the lower price would be shared with energy consumers world-wide, not just with energy consumers in the EC.

While the incidence of an energy tax will fall mainly on consumers in the medium-term, circumstances may be rather different when the tax is imposed on CO_2 emissions. Such a tax will fall more heavily on coal and peat producers, due to the high carbon emissions from such fuels. As a result, the price of such fuels could fall and there could be increased pressure on marginal producers to close down. This has implications for the coal industry in the UK and Germany and for the peat industry in Ireland.

The carbon tax will affect the Irish economy through a number of channels. Firstly, it will have an *income* effect as it raises the price of energy and thus consumer prices. This will, in turn, cut real disposable income and consumption.

The rise in energy prices will also lead to *substitution* away from energy use both by households and by the productive sector of the economy. In the case of households the elasticity of substitution between energy and other goods is quite low. This means that even with a big rise in the price of energy, consumption of energy will show a relatively small fall and the bulk of the incidence of the tax on energy purchased by the household sector will fall on consumers.

In the industrial sector there will also be some substitution of other inputs for energy in the production process. However, the substitution possibilities are quite limited in the short to medium term so that energy consumption will not show a radical change. Because the Irish industrial sector is a price taker on world markets a unilateral tax would raise industrial costs, reducing competitiveness and, therefore, output. However, if the tax is imposed as part of an EC wide environmental plan, competitiveness within the EC would be unaffected and the loss of output could be quite small.

In addition to the standard income and substitution effects the tax will set in train a dynamic process which will have wider effects on the economy. The rise in consumer prices will trigger demands for wage increases. Depending on whether the tax is imposed unilaterally or multilaterally and depending on the response in other countries, these could result in a loss of competitiveness and output. An EC tax would encourage further research into energy conservation measures and into alternative non-polluting forms of energy. Finally, the revenue accruing to the state could either reduce debt and future debt interest or it could be used to reduce taxation or increase other expenditure.

The effects of independent action by Ireland in introducing a carbon tax would be rather different than if there were a simultaneous introduction throughout the EC. For example, Irish firms which are energy intensive would lose competitiveness *vis à vis* their EC counterparts. The EC price level would remain unchanged whereas the Irish price level might rise posing additional problems. In Section 5.4 we first consider the effects of such a unilateral tax where Ireland is assumed to act alone.

In Section 5.5 we consider how the results might be modified if, as proposed, the carbon tax were imposed on an EC wide basis. In this case the competitiveness of the Irish economy compared to our EC partners would be unchanged. However, the rate of growth of output, employment, and inflation within the EC could be modified and this would have an important indirect effect on the Irish economy.

The imposition of a carbon tax would result in a major increase in revenue for the exchequer from indirect taxation. Under the EC proposals this revenue would be available to the Irish government to use in a number of different ways. Depending on how it is used there may be quite different effects on the Irish economy in the medium term.

In this chapter we consider two alternative ways of spending the money. These are described in Section 5.4. The first involves using the additional resources to repay debt. While this approach would be contrary to the EC intention that the tax should be revenue neutral, it represents an, albeit unlikely, polar case. The second option is to use the revenue to reduce social insurance contributions. This is more in the spirit of the EC Commission's proposals. In between these polar cases is a myriad of other options. While we have analysed a number of other possibilities, such as using the revenue to cut VAT rates (mentioned below), the effects of other ways of spending the revenue are likely to lie between the two polar cases considered here.

5.4 Simulations - Unilateral Action

In assuming a unilateral imposition of the tax any changes in the cost of production affect Ireland's competitiveness *vis à vis* its EC partners. It also means that the output price of the industrial sector remains unchanged - producers can not pass forward some of the incidence of the tax to consumers in Ireland or abroad. Finally, any adverse affects on output and employment in other EC states, which would affect domestic production and the domestic labour market, are ignored.

The benchmark forecast for the period 1991-2000 underlying this analysis was published in the ESRI's *Medium-Term Review* (Bradley *et al.*, 1991). The different tax scenarios are superimposed on this benchmark and the results are presented below as changes compared to this benchmark. Thus when we talk about the volume of GDP being reduced by 1 percentage point by the year 2000 we mean that GDP in that year would be 1 percentage point lower in absolute terms than it would have been without the tax change.

In this simulation the carbon tax is imposed on all domestically produced energy as well as all imported energy. For simplicity we assume that the tax is introduced in 1991 rather than phased in gradually from 1993 to 2000, as proposed by the EC Commission. This gives a better opportunity to examine the likely medium-term effects of the tax using the model as the full effects will take many years to work themselves out.

Energy Tax with Repayment of Debt

In this simulation the government is assumed to use the additional revenue to reduce the foreign component of the national debt. The effect of the tax on the prices of the different fuels has already been discussed in the Preface to this paper. The revenue from this tax accrues to the national government rising from around £460 million in 1991 to around £740 million by the year 2000. Revenue from indirect taxes increases by between 8.5 per cent and 10.0 per cent over the period. The sectors, on which the energy tax is levied, are assumed to be uncompensated by the government for the additional taxation that they bear.

The effects of these uncompensated energy taxes on the economy are shown in Figure 5.5. The initial impact is to dampen the level of economic activity and increase the level of prices and wages in the economy. Both GNP and GDP fall below their benchmark levels in Fig 5.5a. GNP falls to a low of about 0.5 per cent below the benchmark by 1994 and recovers thereafter until 2000 when it is only 0.15 per cent below the benchmark. GDP continues to fall throughout the period so that it is almost 1.0 per cent below the benchmark by 2000. The divergence between the two measures is due to the government using the revenues from the tax to repay the foreign component of the national debt. This reduces foreign interest payments on the debt so reducing the net factor outflows which drive a wedge between GDP and GNP.

The increase in revenue from the energy tax increases the government surplus as a percentage of GNP (reduces its deficit) by between 1.4 and 1.8 percentage points compared to the benchmark in Fig 5.5d. As this surplus is used to repay debt, the debt/GNP ratio is reduced steadily throughout the period in Fig 5.5e. By 2000 it is almost 12 percentage points lower than in the benchmark.

The additional taxes in the economy raise the level of consumer prices by around 1.5 per cent compared to the benchmark in Fig 5.5b. The increase in the level of consumer prices occurs over the first four years of the imposition of the tax; thereafter the rate of inflation is unchanged. In response to the price increase wages in the economy initially rise by about 0.4 per cent in 1992. However, rising unemployment puts downward pressure on wage rates so that they show little change compared to the benchmark by the end of the period.

The impact of the slow-down in economic activity leads to a steady reduction in total employment and an increase in the unemployment rate in Fig 5.5f and Fig 5.5g. Total employment falls initially by 0.3 per cent from the benchmark in 1992. By 2000 the level of employment is 12,700, or just over 1.0 per cent, below the benchmark. Approximately a third of the employment loss occurs in the industrial sector. The other two thirds occurs in the market services sector.

The unemployment rate as a percentage of the labour force rises by 0.45 percentage points compared to the benchmark by 1994. Thereafter the unemployment rate declines slowly as emigration from the country begins to pick up in Fig 5.5h. This assumes that the UK labour market is unaffected as the tax is imposed unilaterally in Ireland. By the year 2000 the numbers unemployed are falling due to the increased level of emigration.

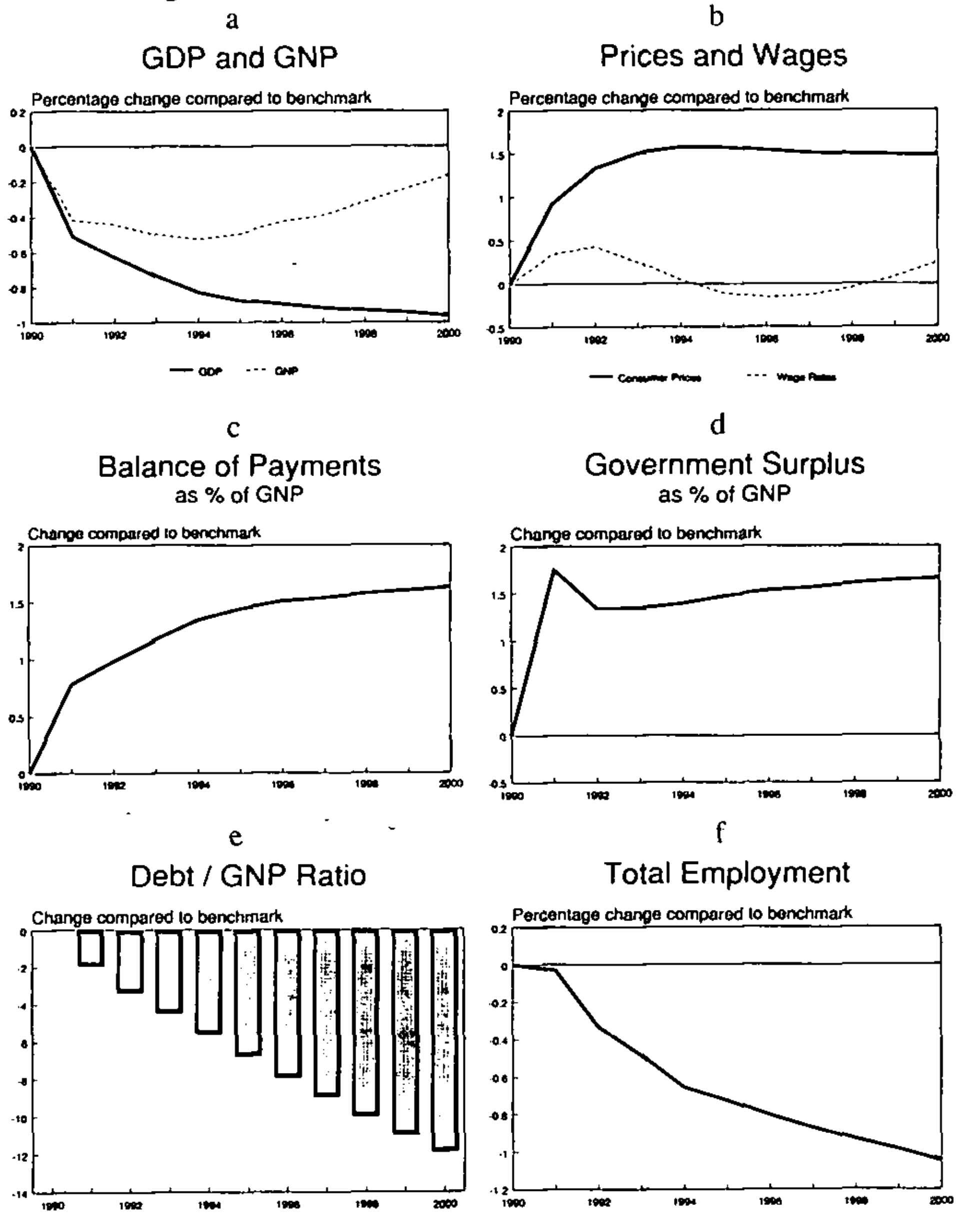
Ireland is a net importer of energy so reduced energy demand and reduced foreign interest payments on the national debt steadily improve the Balance of Payments (BoP) as a percentage of GNP in Fig 5.5d. The BoP surplus is increased by over 1.6 percentage points of GNP by 2000.

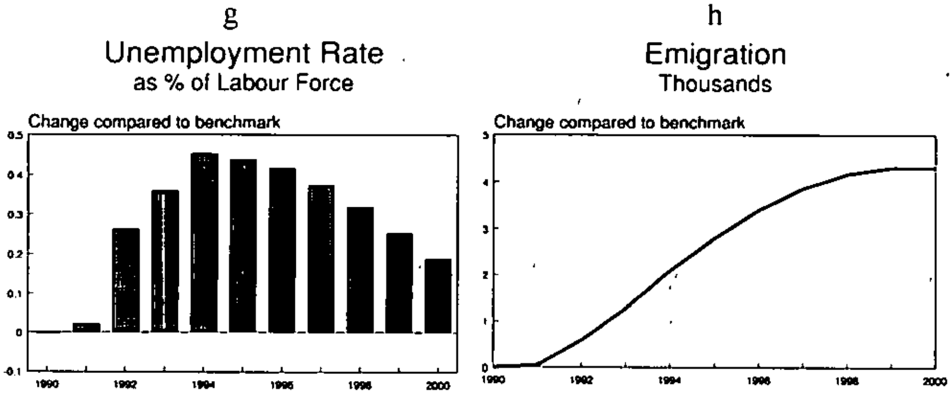
In this simulation we have assumed that Ireland is locked into the EMS so that Irish interest rates are set equal to German rates in nominal terms. The improved financing position of the exchequer has no impact on domestic interest rates. Instead it is reflected in a growth in the net foreign asset position of the state. The rise in the inflation rate temporarily reduces the domestic real interest rate below the benchmark level which has some beneficial effects.

Half of the incidence of the energy tax falls directly on domestic consumers in the form of higher prices. The other half of the incidence falls on the productive sector, particularly on the services sector.

On the basis of the assumed elasticities of demand for energy, this tax results in a reduction in energy demand of 3.4 per cent compared to the benchmark by 2000. Because the composition of fuels used by the different sectors in this simulation is assumed to be insensitive to price changes in the medium-term, that is there is no inter-fuel substitution, the volume of CO_2 emissions also falls by 3.4 per cent. In reality, substitution of low carbon for high carbon fuels could be expected to lead to a somewhat bigger reduction in emissions in the medium term.

Figure 5.5: *Simulation One : Uncompensated Energy Tax*





The demand for the output of Irish industry is dependent on exports to other countries. In this simulation it is assumed that the carbon taxes are imposed unilaterally by Ireland so that industry is unable to pass on the tax to its foreign consumers. This affects its profitability and its competitiveness on world markets. If the taxes were imposed multilaterally, as EC prices rose, Irish industry could pass on more of the incidence to its foreign customers without losing its competitiveness.

Energy Tax with Reductions in Social Insurance Contributions

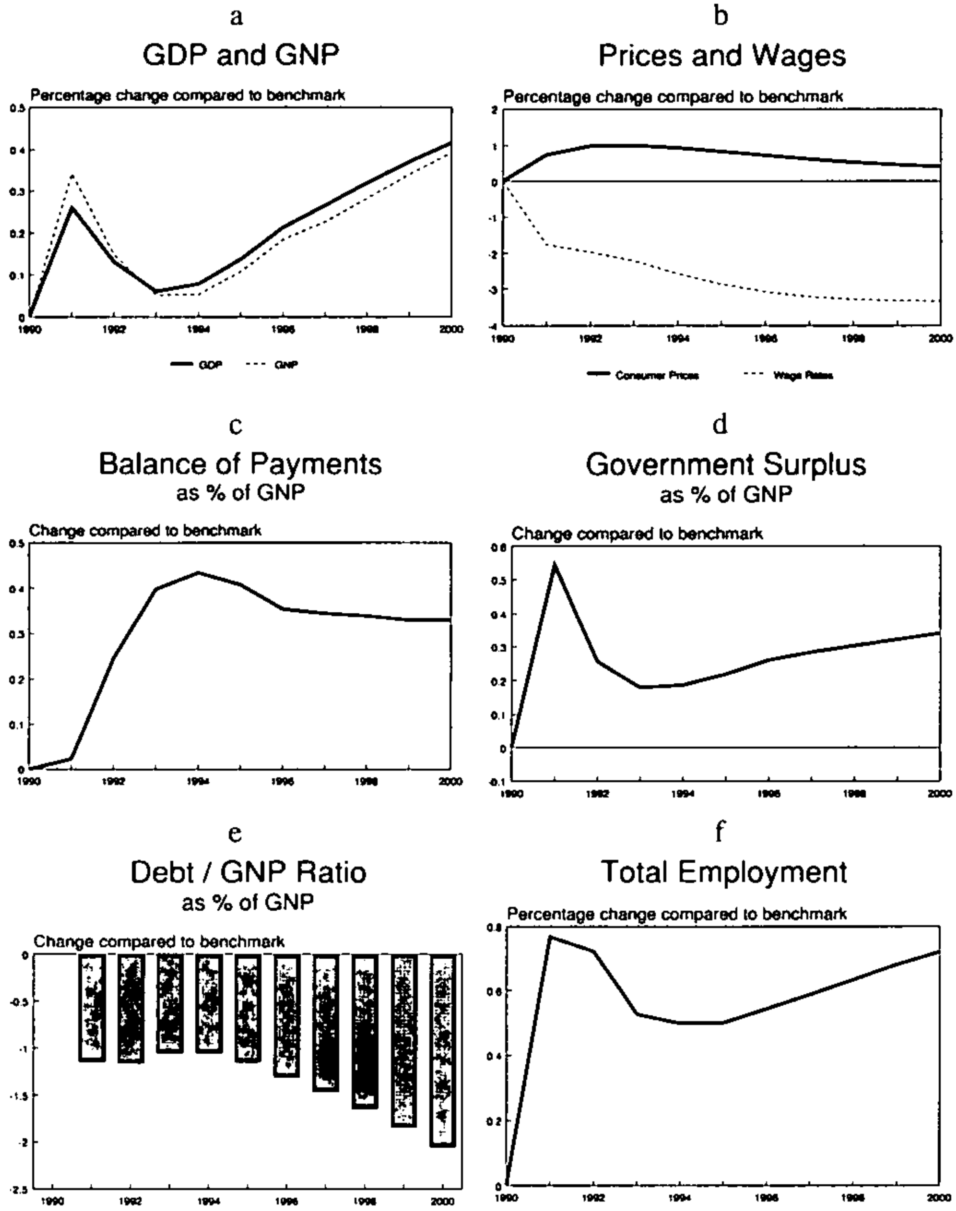
This simulation assumes the same carbon tax as in the previous example. In this case the revenues from the tax are assumed to be used by the government to reduce the level of social insurance contributions, in Ireland this is called Pay Related Social Insurance (PRSI). An alternative simulation was carried out where the VAT rate was cut instead of social insurance contributions. However, the results were rather similar in character to the case discussed here though the magnitude of the increase in employment and GNP was significantly smaller.

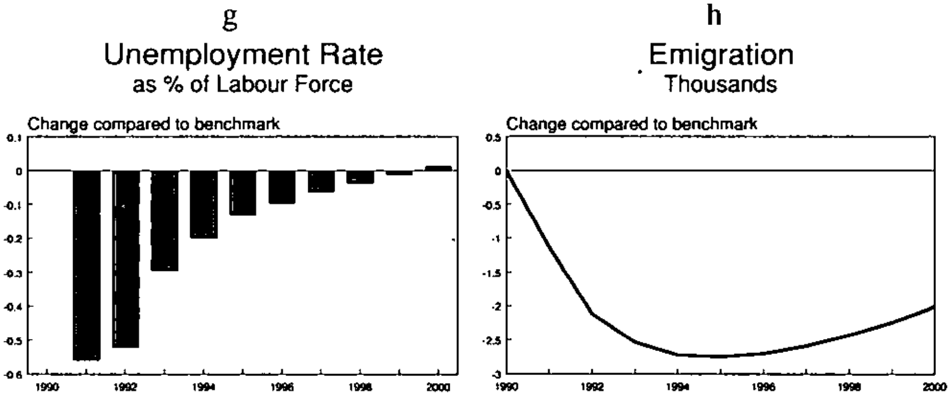
The key to the impact of the revenue neutral restructuring of the Irish tax system discussed here lies in where the incidence of the tax changes falls: who in reality pays the tax. In the case of energy taxes, because the industrial sector is not very energy intensive, it ends up paying a relatively small share of the tax. This happens in spite of the fact that industry cannot recoup the cost of the tax by raising prices.

Industry, on the other hand, is a big employer of labour and, as a result, it would be a major beneficiary from a reduction in labour costs arising from lower social insurance contributions. In the case of a reduction in VAT the effects on the industrial sector would be more attenuated. VAT reductions result in lower prices which, in turn, reduce wage rates in the medium term. However, a significant share of the benefits of the price reduction would flow to individuals outside the labour force so that, for a similar magnitude of tax reduction, the effects on labour costs are somewhat smaller.

This switch in the tax burden from labour to energy would have a positive impact on the Irish economy. This should not be a surprising result given that Ireland is a net importer of energy, as stated above, its industry is not very energy intensive, and it has high taxes on labour, a factor in excess supply.

Figure 5.6: *Energy Tax with Reductions in Social Insurance Contributions*





The net effect of this restructuring of the tax system is to improve the competitiveness of the industrial sector. Firstly, there is some shifting of tax burden away from that sector to services or households. Secondly, because the elasticity of demand for labour is greater than that for energy in the medium-term, it is to be expected that the deadweight losses associated with the tax system would be reduced. The change in relative factor prices results in higher employment and a limited fall in energy demand. The improved competitive position of the sector leads to increased industrial output and exports.

As shown in Fig 5.6a both GDP and GNP grow rapidly in the first year of the tax change. By 2000 both GNP and GDP are 0.4 per cent higher than the benchmark. The changes in GDP and GNP are identical in this simulation as there is relatively little change in foreign debt interest payments as the debt/GNP ratio is held broadly unchanged in Fig 5.6e. This reflects the fact that the revenue from the energy tax is recycled, though the government's financial position does improve slightly due to the higher rate of growth in Fig 5.6d.

If the revenue were recycled through a reduction in VAT the increase in GDP and GNP by the end of the decade would be between 0.15 per cent and 0.2 per cent with little change in the debt/GNP ratio..

With reduced social insurance contributions wage rates are reduced initially by 1.8 per cent below the benchmark in Fig 5.6b.[3] The effect on wage rates increases during the period so that in 2000 they are 3.3 per cent below the benchmark. This reflects the fact that employees bargain in terms of their after tax real wage. The benefits of the reduction in social insurance contributions are shared between employers and employees.

[3]Wage rates are defined as *including* employers social insurance contributions.

The increase in employment in Fig 5.6f leads initially to more than a 0.5 percentage point fall in the unemployment rate below the benchmark level in 1991. However, emigration over the period is reduced by between 2,000 and 3,000 in Fig 5.6h resulting in an increase in the labour force. This in turn whittles away the improvement in the unemployment situation so that the unemployment rate has returned to the benchmark level by 2000.

The balance of payments surplus as a percentage of GNP increases by between 0.3 and 0.4 percentage points compared to the benchmark. The volume of energy imports is reduced by the fall in domestic energy demand.

The effect of this restructuring of the tax system is to reduce energy demand and CO_2 emissions by 2.7 per cent by 2000 compared to the benchmark. This reduction is smaller than in the case where the tax revenue is used to repay debt, reflecting the fact that GNP is higher where the tax revenues are recycled.

5.5 Multilateral Imposition of an Energy Tax

In the simulations described above we have assumed that the carbon tax is imposed unilaterally. However, it is most unlikely that the tax would be introduced in this fashion. The EC Commission proposals would involve a simultaneous imposition of the tax in all EC members. Because of the openness of the Irish economy the indirect effects from the imposition of the tax in other EC members could be as significant as the direct effects described above.

As discussed in Chapter 4, the effects of such a tax on the EC economy in the medium to long-term will differ significantly depending on whether the tax is imposed at a global or at purely an EC level. This would, in turn have implications for Ireland.

To analyse the effects of a multilateral or EC wide imposition of a carbon tax requires a suitable model of the EC economy. As described in Chapter 3 by Bradley, a number of preliminary attempts have been made to quantify the effects of such a tax at the level of the EC. However, as mentioned by Bradley, considerable uncertainty surrounds them. They generally suggest a small negative effect on GNP, though in some cases and for some countries the effect may be positive.

There are many different channels through which an EC wide tax would affect the Irish economy. Compared to the unilateral tax it would affect Ireland's competitiveness, the growth in external demand facing Irish industry, tourism, the external price environment, and it could also affect German interest rates and the UK unemployment rate, both of which have significant effects on the Irish economy.

In the unilateral case examined above, Irish competitiveness disimproves in the case of a carbon tax where the revenue is used to repay debt; when the revenue is used to fund a reduction in PRSI competitiveness actually improves. Fitz Gerald and McCoy (1991) suggest that in the case of a revenue neutral tax the change in competitiveness accounts for up to a 0.2 per cent change in GNP by the year 2000. In the case of a multilateral imposition of a revenue neutral tax package one would expect on *a priori* grounds that there would be no improvement in Ireland's competitiveness.

The traditional mechanism for external economic changes to affect the Irish economy is through their effects on growth and prices. If the efficiency of the EC tax system were improved by the substitution of a tax on energy for a tax on labour and the EC growth rate rose, this would clearly increase the demand for Irish goods. A carbon tax would also greatly increase the cost of travel and transport and this would have adverse effects on the volume of tourism and trade.

Any rise in EC prices could raise import prices and could permit Irish firms to pass on part of the cost of the energy tax rise to consumers in Ireland and elsewhere in the EC. This would almost certainly raise the long run inflationary effect of the tax to over 2 per cent. This could result in a rise in nominal interest rates throughout the EC. However, much would depend on the effect on real interest rates in the EC in the medium term.

Finally, the labour market effects in other countries, in particular the UK, would affect the Irish economy through the migration mechanism. If the shift in the burden of tax from labour to energy resulted in higher employment this could lead to higher emigration and lower unemployment in Ireland in the medium-term.

In considering how an EC wide shift to a carbon tax, away from taxes on labour, would affect the Irish economy much depends on the efficiency of the present tax system in other EC countries. If, as in Ireland, there are opportunities to improve efficiency in other EC countries by tax reform, then the proposed carbon tax is unlikely to have an adverse economic impact. However, the evidence cited in Chapter 4 discounts this effect.

The corollary of the likely small economic impact of the proposed tax is that it may not have a major effect on CO_2 emissions. The work by OECD cited in Chapter 4, indicates that a carbon tax many times the size of the EC proposal would be needed to meet the objective of stabilising carbon dioxide emissions in the next thirty years. The effects of such a huge change in the tax system would be much more likely to reduce growth along the lines suggested in Chapter 4.

5.6 Conclusions

Results in this chapter indicate that for Ireland, given the distortions in the existing tax system, a unilateral move to reform our indirect tax system, possibly including a carbon tax, is desirable with any additional revenue being used to reduce taxes on labour, in particular social insurance contributions. Certainly, if a carbon tax were introduced at an EC level it seems probable that it would, if anything, benefit the Irish economy through improving the efficiency of the tax system. Given the low energy intensity of industry, the fact that Ireland is a net energy importer, and the nature of the labour market, the beneficial effects for Ireland of the restructuring of the tax system are not surprising. However, the magnitude of the economic effects is quite small given the extensive nature of the tax reform examined here.

As discussed by Scott in Chapter 2, the incidence of the costs and benefits of such a tax change could be quite uneven. Unless some of the additional revenue from a carbon tax were used to mitigate its effects on low income households, the results could be regressive.

As shown in Table 5.5, our research suggests that a unilateral introduction of a carbon tax, combined with a reduction in social insurance contributions, would raise the volume of GNP by 0.4 per cent by 2000. There would be an increase in numbers employed of around 9,000. The eventual effect on the rate of inflation could be quite low; gross wage inflation would adjust downwards as employees take account of the reduction in their tax bill (from lower social insurance contributions) leaving their real after tax wages unchanged.

The results presented above suggest that the tax, at the level proposed by the EC Commission, would not achieve a major reduction in energy consumption or CO_2 emissions. However, further research is needed into the possibility of fuel switching. It is likely that, if anything, we have underestimated the possibility of reducing CO_2 emissions through fuel switching and conservation of energy. In addition, it is probable that, given a somewhat longer time frame, the reduction in energy consumption achieved could increase as the fruits of new research come on stream.

The EC have suggested an objective for Ireland of limiting CO_2 emissions to a ceiling of 15 per cent above the 1990 level. In spite of the caveats, the results of our study point to a major problem for Ireland in meeting this objective by the year 2000, even with the help of the carbon tax. The benchmark forecast for CO_2 emissions growth over the period is 24 per cent, however the carbon taxes simulations examined in this chapter would only reduce this forecast by between 2.7 - 3.4 per cent, leaving the emissions well above a 15 per cent target level. While our forecasts of CO_2 emissions are uncertain, and probably on the pessimistic side, they do suggest that the costs of meeting the objective will be quite high requiring a substantially higher tax than that currently envisaged by the EC. We have not been able to identify the likely returns to the other energy saving measures proposed by the EC Commission.

Table 5.5: *Effects of Different Simulations for Unilateral Tax, 2000*

Revenue Recycled:	*GDP*	*GNP*	*Total Employment*	*Unemployment Rate*	*Consumer Prices*	*Wage Rates*	*Debt/GNP Ratio*
	%	%	%	% of Labour Force	%	%	
None	-1.0	-0.2	-1.0	0.2	1.5	0.2	-11.9
PRSI	0.4	0.4	0.7	0.0	0.4	-3.3	-2.1

As discussed in Chapter 2, it is important for the future that, whatever the environmental objective decided on by the EC, taxes should be a major instrument in implementing policy. The fact that high taxes may be needed to meet the chosen objective merely reflects the magnitude of the costs imposed on the economy. While recourse to regulations as the major tool of policy may disguise these costs, it will also greatly aggravate them.

It takes the economy many years to react adequately to changes in the relative price of energy. As a result, it is important that there should not be sudden random shocks to relative prices which surprise decision makers in industry and elsewhere in the economy. A planned steady increase in the price of energy and of carbon dioxide emissions would allow the economy time to react as individual companies and citizens plan for the future and undertake suitable research. It would also provide a warning for industries which face major adjustment problems.

As discussed, in Chapter 3 by Burniaux, Martin, *et al.*, if effective action is to be taken to tackle the problem of global warming it will have to be done at a global level. For the kind of tax increases needed to stabilise or reduce greenhouse gas emissions there are likely to be substantial costs to individual countries. These costs could be aggravated if action is only taken by individual countries or trading blocks.

Finally, it is important that research in this area take account of the wider EC (and world-wide) implications of any change in EC policy. These wider economic effects will have major significance for the Irish economy and can only be estimated in the context of a suitable model of the EC or world economy.

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Chapter 6

COMMENTS

Comments By: Frank Convery

General

I would like to congratulate the contributors for a fascinating series of contributions. It gives me particular pleasure to see ESRI taking a lead in this area of linkage of economic and environmental policies, and doing so in the context of the macro model. As an "alumni" of ESRI, and as an enthusiast both professionally and personally for the field of environmental economics, I think the importance of the application of the skills here arrayed for serious analysis of Irish environmental issues, can hardly be exaggerated. I hope that this effort will be continued, and indeed expanded upon. Truth, like peace, comes dropping slow, and the work must be sustained over a substantial period if the most significant benefits are to be garnered. I would like also to congratulate the funders of this work; it is an excellent allocation of resources. Inevitably, the findings will not suit all interests all the time, but, over the long haul, it will allow the taking of rational decisions from which all will benefit. It will also ultimately provide a solid intellectual bulwark from which stupid policies (to which we are occasionally prone) can be resisted.

There is a strong revisionist tide running at present questioning the reality of the "Greenhouse Effect"; it is being argued with some degree of plausibility that the warming is part of a cyclical pattern, which will not be significantly ameliorated by reduced emissions, and that furthermore the costs of the "Greenhouse Effect" *per se* may not be substantial. Such questioning is very useful, but it would be a mistake to allow it to reduce the analytical work implicit in the addressing of the "Greenhouse Effect", for the following reason. I suspect that it can be shown that the measures envisaged to control greenhouse gases are justified in their own right, because there are other substantial global negative externalities arising from the rapid expansion in the burning of fossil fuels. However, this case remains to be made, and will be part of economists' research agenda for the future.

Modelling

The paper by John Fitz Gerald and Daniel McCoy and that of Burniaux, Martin *et al.* both go a long way towards redeeming the reputation of economic-ecological modelling after the disrepute engendered by the exercises carried out on behalf of the Club of Rome in the early 1970s. (Meadows *et al.*, The Limits to Growth, Universe Books, New York, 1972). These early models had little economic feedback, and largely ignored the role of relative prices in changing patterns of production and consumption. As a result, the Club of Rome group concluded that the world would "run out" of key natural resources in a relatively short time. The ESRI and OECD models are much closer to the realities of economic and resource interactions.

However, precisely because their results are so interesting and so relevant, they will have to deal with the "black box" issue. Policy makers, and the producers and consumers affected by the implications of the model outputs - especially those who are likely to "lose" if the findings are acted upon - will have an understandable inclination to challenge the results, and to ask for alternative scenarios. The models are necessarily demanding of skill and experience to work with and interpret. It will be necessary, but very difficult - to address the challenge of demonstrating that the models are not mysterious, irrational "black boxes", and to allow interest groups and others access to the workings thereof, and to the capacity to simulate a variety of scenarios.

There is an intangible called "confidence" which shapes much of economic performance, but yet is very difficult to model. The ESRI findings illustrate the potential gap in this regard. Two scenarios were described: the first posited that the revenues generated by the carbon tax would be used to reduce the national debt, while in the second scenario revenues would be used to reduce payroll taxes. The net economic performance in the latter scenario was dramatically better than in the former, because in effect the latter was reducing the cost of a key economic input across all sectors, while the former was a more static contribution.

However, it is possible that a reducing debt would engender such confidence in the Irish economy that additional investment funds would flow into the country, generating economic activity, and/or savings would increase, allowing a reduction in interest rates. Or, perhaps such a reduction would provide the crucial margin which would allow Ireland to participate as a full member of the proposed European common currency, engendering whatever benefits are to flow therefrom. These points are not criticism of modelling work *per se*; after all, the erratic workings of the collective psychosis called "confidence" have caused more heartburn to economic forecasters of all types and in all eras than any other single variable. But they are an indication of what yet remains to be done, and a warning the so far unmodellable X factors can still confound.

Efficiency and Distribution

Sue Scott's paper showed quite clearly that there would be winners and losers. Amongst the losers of the carbon tax in Ireland would be the peat producing sector, coal agents and low income households. Clearly, some of the proceeds of the tax would in all likelihood have to be applied to compensate some or all of these losers. It is a very useful advance on the usual efficiency analysis to include a contribution on the distributional implications; policy can be devised which allows such issues to be addressed as an integral part of the policy structure. [This seems to have been done with some success in the case of the banning of the sale and distribution of bituminous coal in Dublin, where this has been accompanied by measures to compensate low income households]. This paper also highlights an interesting conflict between local and global environmental imperatives. It is clear that anthracite, which is smokeless and is therefore being encouraged to address Dublin's smoke problem, produces more carbon per unit than smoky bituminous coal.

The Burniaux, Martin *et al.* demonstrate the huge gain to the world economy if carbon quotas are assigned and if trade therein is allowed, rather than attempting to control via regulation. He makes the assumption that the quota for OECD countries comprises existing levels minus 20 per cent, and that those of developing countries are 50 per cent above the existing base. If it is decided to address the global carbon problem seriously, the policy debate in the future will turn on these percentages. There needs to be a companion paper to Burniaux, Martin *et al.* which addresses itself to the equity, efficiency, political and other implications of alternative scenarios in this regard.

It was not part of the authors' briefs to address the other sources of greenhouse gases - methane, CFCs, burning of forests. These comprise important sources, and their control also comprise important parts of the solutions; it is important that a preoccupation with carbon dioxide emissions from fossil fuel burning does not "crowd out" these other dimensions.

Comments By: Donal de Buitleir

Introduction

I also wish to congratulate the authors on their excellent papers. We are at a very early stage in the important debate on energy and carbon taxes and I think this morning's conference has got us off to a very good start. I learned a great deal from reading the papers. To take one example, I had never realised before how important China was as a generator of carbon dioxide emissions.

Trade in Emission Rights

Burniaux, Martin *et al.* paper clearly shows the importance of having trades in emission rights and he demonstrates the benefits of this very clearly. There is a case for extending either credits or payments to countries which are now or could potentially become net carbon acceptors. For example, there is a case for the developed world considering the possibility of paying countries not to cut down their rain forests. Indeed, there is a whole series of bargains that could be undertaken between the north and south of the world. To take one example, about one-third of CFCs are generated by refrigeration. China, India and Brazil, to name just three very populous countries, are about to embark on major refrigeration programmes. It seems to me there is a strong case for aid from the north of the world to these countries to try and get them to adopt the cleanest technology in this area. Potentially, the making of such bargains has implications for the uses of funds raised from green taxes. In the longer term we should not assume that we will be able to use the money generated from green taxes domestically because we may have to provide funds to less developed countries to enable them to behave in an environmentally sensitive way from a global point of view.

Taxes v Regulation

I strongly favour the use of taxes rather than regulation in the area of pollution. The arguments for this are well known. You get a better return per £ invested. Polluters have a continuing incentive to improve rather than just meet the regulatory standard and in general the system is much more flexible. However, economists and policy makers may have difficulty convincing the public that taxes are superior to regulation and I think we all have some serious work to do in this area. For example, the success of dealing with smog in Dublin is likely to reinforce the public perception that the regulation route is a better one.

There can be a clash between the Revenue-raising objectives of taxation and choosing an environmental tax at the optimum level as far as pollution is concerned. To balance these conflicting requirements needs very clear official thinking which is not always apparent in cases in which objectives may be in conflict. For example, there has been confusion in public policy-making in relation to State-sponsored bodies where government has found it difficult to balance its interests as a shareholder with its duties as a regulator.

EC Proposal

My general reaction to the EC proposal for an energy carbon tax is that it is a sensible one. It uses the tax system and it is also phased which gives people some time to adjust. From Ireland's perspective where we have relatively high energy taxes, the question needs to be asked as to whether this energy carbon tax is applied to the existing base or whether or not there might be a case for differential EC taxes on energy to ensure that energy prices were at the same level across the community.

Distributional Issues

Sue Scott's paper dealt with very important distributional issues. On a technical point, I would like to see the figures done on the basis of the equivalence scale adjusted household budget survey. I am not sure if it would make any difference but it would be useful to see if the results are sensitive to that adjustment which I think gives you more conceptually valid results.

Having no tax on energy or a very low tax on energy is a very bad way of protecting the poor. The policy issues in this area were considered by the Commission on Taxation in its third report where they examined the question of putting VAT on food. Expenditure on food is as regressive and perhaps even more regressive than expenditure on energy but exempting food from VAT is a very bad way of protecting the poor. For example, roughly £85 of every £100 spent on food is spent by people who are not poor. Even though the poor spend a higher proportion of their income on food, the fact remains that the rich spend absolutely more but relatively less. It seems to me that there are much more efficient ways of helping the poor than exempting energy from taxation.

In any event, it looks as if we are now going to have major reforms of the tax system over the next few years. This provides the opportunity of putting together sensible and coherent distributional packages together.

An argument that is often put forward is that optimal tax theory implies that the deadweight burden of taxation is minimised if taxation is levied on items, the price elasticity of demand of which is very low. My feeling is that this argument does not apply if the level of taxation is related to the externality involved. This is very important in the energy area where the whole basis for higher taxes on energy is related to the externality argument.

Policy Implications for Ireland

I am convinced by John Fitz Gerald's and Daniel McCoy's argument that we should use the revenue raised from energy taxes to cut PRSI. There is a strong feeling in this country that we don't need to worry about PRSI in Ireland because it is relatively low. This point has been made frequently by a number of commentators. I think this view is mistaken. Just because other countries hobble themselves by taxes doesn't make it sensible for us to do likewise. The benefits from reducing PRSI in Ireland are particularly strong given the openness of our economy and the high rate of unemployment. In fact it seems to me one of the implications of the paper that we should go ahead unilaterally and increase energy taxes to cut PRSI subject only to the constraint that we don't generate the levels of cross-border shopping that arose in the 1980s.

Conclusion

My conclusion is that we should raise energy taxes in Ireland. The first step is to raise energy items to the standard rate of VAT. At present they are at the lower rate of VAT. Before special taxes are imposed it is only logical to get these items into the normal tax regime. After that there is a case for increasing excises on energy and using the proceeds to cut PRSI. A matter for debate is whether we need to cut employer or employee PRSI. In theory I don't think it matters on the basis that the burden of PRSI is borne by the employee. However, I think it matters politically and for that reason it may be important to cut employee's PRSI.

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