THE DAVID HUME INSTITUTE

The Economics of Climate Change Policy in Scotland

Nick Hanley

October 2007

Hume Occasional Paper No 73

The David Hume Institute
25 Buccleuch Place
Edinburgh EH8 9LN

ISBN 978 1 870482 74 5

The Economics of Climate Change Policy in Scotland

Nick Hanley

The David Hume Institute 2007

Foreword

The idea for this report emerged early this summer, in conversation between our Chair of Trustees, Eileen Mackay, and Sir Gerald Elliott of the Binks Trust. As discussed with Sir Gerald, there is no shortage of reports on the possibility of global warming, its possible causes or its possible implications. However, there did not appear to be a comprehensive document setting out the possible means of reducing emissions in Scotland, across sectors, and the implications of such measures for the economy and for business.

Given this gap, we approached Professor Nick Hanley at Stirling University, who is pre-eminent in the field of environmental economics in Scotland – and highly respected across a broader canvas – to see if he would help us to plug the gap. Nick was keen to take on this task and he has worked highly efficiently and effectively to deliver the attached document. We are in his debt.

I am most grateful to Professor Brian Main, our Academic Director, and Professor Donald MacRae, Trustee of the Institute, who both served on the steering group for the research. I must also thank Lesley Sutton, the newly appointed Research Officer at the Institute, for overseeing the project and liaising closely with Nick Hanley as the paper developed. We are extremely grateful to the Binks Trust for their sponsorship of the research project and this publication.

This paper is to be discussed at a seminar on 15th November 2007 at the Royal Society of Edinburgh. That seminar is kindly sponsored by the Economic and Social Research Council; our thanks to Lesley Lilley at the ESRC for her usual support and co-operation. Professor Nick Hanley will be the key speaker at the seminar, to be chaired by Professor David Sigsworth.

Nick Hanley's paper is remarkably comprehensive but also as accessible as is feasible for such a complex and technical topic. It includes a substantial executive summary, but I would encourage the reader to press on beyond this summary to the full report. This starts off with a careful statement of the present and prospective position regarding Greenhouse Gas (GHG) emissions in Scotland. The largest source is energy supply (proportionally higher than for the UK as a whole), followed by transport, business, agriculture and residential. So far as recent performance is concerned, Nick notes that Scotland's net GHG emissions reduction recently have been greater than all EU states other than Germany and the UK as a whole. Interestingly, transport's share of total emissions has risen while industry's has fallen.

The paper also provides details of the targets faced within Scotland and current policies at UK and EU levels. That is followed by a very important chapter on the basic principles of the economics of pollution control.

Without going into the detail, his conclusions can be summarised as follows:

If Scotland wants to hit its targets for cutting GHG emissions at the lowest cost to the economy then policies need to be adapted which:

- put a price on pollution, and a value on pollution production;
- allow the lowest cost options for cutting emissions to be realised first;
- allow flexibility of response across firms and recognise that emissions reductions come at very different costs across polluters; and
- are capable of equalising the additional costs of reducing pollution across sectors.

These basic principles are critical to his discussion of the three types of approaches to emission reduction – namely economic instruments (taxes or tradable permits), regulation and voluntary approaches. Hanley inevitably favours the economic approach, setting out his justification clearly and effectively. He then compares and contrasts carbon taxes and tradable carbon permits and also carefully considers the evidence as to whether economic instruments, so desirable in principle, actually work in practice! This is followed by a sector by sector analysis of practice and theory, yielding important conclusions and implications for policy makers.

In his final sections Nick Hanley considers ‘adaptation’ as an alternative to emission reduction for a country like Scotland and then pulls out some implications for business. We may not be able to judge whether adaptation would be a more cost-effective solution than emission reduction, given the need to make assumptions about the extent of climate change and its impacts. That may not matter too much, if it is agreed that at least participating in global and EU measures to reduce emissions is politically desirable; but nevertheless the discussion merits our attention.

We see this report, and the associated seminar, as a considerable and constructive contribution to a continuing debate. By making no analysis of assumptions about the science we try to avoid controversy and are able to focus on the theory and policies. We commend Nick Hanley’s paper to your attention.

As usual I most close with the caveat that, whilst we at the David Hume Institute are delighted with this report and certainly convinced that the subject matter merits this type of careful and rigorous analysis and attention, as a charity the Institute can hold no collective view on either the subject matter or the policy issues and implications.

Jeremy Peat
Director

The Economics of Climate Change Policy in Scotland

A paper for the David Hume Institute

Nick Hanley, Professor of Environmental Economics, University of Stirling

With contributions from Simon Hart (UPM-Tilhill) and Professor Pete Smith (University of Aberdeen)

Thanks to some of my current and former graduate students for excellent research assistance:

Ariel Bergmann, Ian MacKenzie, Mavra Stithou, and Elena Tinch.

and to Professor Brian Main, Jeremy Peat and Lesley Sutton for comments and contributions.

October 16th 2007.

Executive Summary

- This paper tries to respond to the issue of global climate change?' This involves looking at how Scotland responds to EU/UK targets for reductions in carbon emissions as well as considering where the balance should be struck between reducing green house gas (GHG) emissions and taking actions to reduce future impacts. Key sector issues are also discussed as well as what actions make sense for Scotland to undertake on its own.

- Energy production, transport, agriculture, business and industry, and households are the main causes of GHG emissions in Scotland. The transport sector's share of total emissions has risen, whilst industrial emissions have fallen.

- The UK faces a target set by the Kyoto Protocol to reduce emissions of CO_2 equivalents by 12.5% over the period 2008-2012 relative to 1990 levels. The Scottish share of this is a cut of around 1.7m tonnes in annual savings by 2010, although the Executive wants to exceed this. At the UK level, a more ambitious target of a 60% cut by 2050 was set in Energy White Paper in 2003. Eighty four percent of total GHG emissions in Scotland are accounted for by carbon dioxide CO_2. Nitrous oxide and methane emissions make up a further 8% and 6.7% respectively.

- The economic theory of pollution control revolves around the idea of cost minimisation. Since we cannot determine the optimal level of pollution reduction due to a lack of information, the aim is to hit a pre-determined target at the lowest social cost. These social costs can be thought of in terms of abatement costs and can relate to (1) the costs of using cleaner inputs in production, (2) installing and operating pollution abatement equipment and (3) the costs of reducing output. For households, abatement could come about by investing in energy saving e.g. cavity wall insulation, taking less foreign holidays by plane, moving to a smaller house or changing travel-to-work mode. Whilst some of these activities may generate net cost savings over time, most are costly. **Economic theory**, highlighted fully in the report, indicates that *'the social costs of reducing pollution will be minimised when marginal abatement costs are equalised across all polluters'.*

- How could cost-minimising be achieved **in practice**? One option is for the government or environmental regulator to tell firms by how much to cut emissions. But this would require the government to know the marginal abatement costs of every polluter to minimise social costs. This is an impossibly large information requirement. Thus, this 'command and control' approach will not be economically efficient, even though the government does impose regulations on pollution control.

- Economists believe that setting a tax on pollution or issuing tradeable permits i.e. by making use of 'economic instruments' or 'market mechanisms' can bring about a cost-minimising outcome by providing flexibility and aligning private motives with public gain. Both allow firms to choose their own best response to either the tax or the permit market. By operating in this de-centralised environment, society gets its pollution reduction for a lower price than would be the case under command and control

- Are carbon taxes better than tradeable carbon permits? One advantage of taxes is that, so long as they are levied high enough up in the supply chain, they send signals to all activities that emit carbon, no matter what the size of the polluter. It has also been argued that a carbon tax should be associated with higher expected benefits than a tradeable carbon permit, whilst taxes also raise money for the government and may be designed with fiscal neutrality in mind. The 'double dividend' effect arises when a pollution tax allows a reduction in pollution and a rise in revenue, but also provides governments with the option to reduce other taxes. If the taxes reduced are distortionary, such as labour taxes, then a secondary benefit arises in the form of reduced deadweight losses in the labour market.

- However, there are a number of arguments against environmental taxes:
    - They may impact negatively on competitiveness, although the evidence suggests that such effects for CO2 are rather small.
    - Governments do not start with a clean slate. Energy use is already taxed in many countries which complicates how to introduce a new tax on greenhouse gas emissions.
    - Environmental taxes may have adverse distributional effects, especially in terms of their impacts on lower income groups.
    - One major difference between pollution taxes and tradeable permits is the degree of certainty over whether a GHG reduction target would be achieved.

- A tradeable permit system is also not without problems. One issue with permits is that a baseline must be agreed and set. Baselines are important as they determine the quantity of permits, but what should the reference point be? A further issue is that we might expect the price of tradeable permits for pollution to be volatile. The supply of permits is fixed, whilst demand is rather inelastic, since substitution away from carbon intensive fuels is difficult in the short run.

- Economic instruments to control pollution are being employed more widely across the globe. A report by the US National Centre for Environmental Economics found that direct fees and taxes are the most used economic instruments internationally whilst pollution permit trading regimes have gained greater acceptance worldwide. Greenhouse gas emission control is an important and rapidly growing application of economic instruments. But do they actually work?

- Because carbon trading systems are very new, it is difficult to assess how successful they will be. In addition, no country has set a carbon tax high enough to achieve its Kyoto targets. One of the biggest experiments in pollution control came in the US in 1990, with the introduction of a 'sulphur trading' programme to reduce SO_2 emissions from power stations by 50%. The volume of trading has risen over the life of the scheme and estimates suggest that the benefits of the scheme have been considerably in excess of the costs – a positive result.

- Under the terms of the Kyoto Protocol, the European Union agreed to reduce GHG emissions by 8% from 1990 levels by 2012. One mechanism used to reach this target is the establishment of the *European Union Emissions Trading Scheme* (EU-ETS).

Under the scheme regulated companies from all 25 member states can freely trade allowances but must have, at the end of the compliance periods, enough permits to cover their own emissions or a penalty is imposed.

- To increase flexibility and lower compliance costs, the EU-ETS can also be linked to other mechanisms under the Kyoto Protocol, such as Joint Implementation (JI) and Clean Development Mechanisms (CDM), which allow a greater variety of low compliance alternatives and improve liquidity in the market.

- EU-ETS trading dominates carbon trading at present. Carbon prices fell dramatically in April/May 2006 after it was highlighted that the overall market was in an excess supply position with countries having issued more permits than were being used. The price of carbon fell from 30 Euro to less than 12 Euro per tonne. Allowances have been cut back for phase 2, which will raise the carbon price going forward. Most participants generally support the scheme, albeit with some reservations, and economists applaud the emergence of a tangible ‘price for emissions’.

- Within the UK, current **policy** on climate change includes the EU-ETS as highlighted above, Climate Change Agreements, the Climate Change Levy on industrial use of energy, and energy policy targets and measures. Clearly, there are a number of different initiatives underway to reduce GHGs in the UK and Scotland. Our theory is that a cost-effective control policy for GHG emissions is one which balances marginal abatement costs (MACs) across sources. Can this be applied to sectors of the Scottish economy?

- **Industry** – For those sectors which are part of the EU-ETS scheme, we can measure marginal abatement costs for GHG emissions by considering the price of permits, since logic dictates that no firm will engage in costly emissions reduction if the cost per tonne exceeds the price of carbon permits. In Scotland, 81 companies are covered by the EU-ETS and a further 21 will be included in phase 2, accounting for 50% of Scottish CO_2 emissions. The current permit price is 21 Euro (£14) per tonne CO_2. This represents the cost of increasing emission control in these sectors, since over time companies will rationally adjust their emissions to the point where their own MAC is equal to this permit price. MACs will vary considerably across and within all sectors but no information is available on the current distribution of these costs or how they will change over time.

- **Housing** – Housing energy use in the UK has risen over the past 30 years, mainly due to growth in energy demands for space heating, appliances and lighting. Households have been encouraged to invest in energy efficiency, saving money in the long run. Despite this, uptake of energy saving opportunities has been low. Since households do not face the full social cost of their energy use – due to market failure – it is likely that the level of investment in energy efficiency which households choose to undertake is, from society’s viewpoint, not sufficient. An Oxera report (2006) highlighted that energy savings did not appear to be an important factor in motivating households and many were badly informed on the costs and benefits – overestimating costs. Oxera found that all investments in household energy savings had net benefits over time.

Therefore, the benefits of reducing energy consumption in peoples' homes exceed the costs and should be encouraged as part of any climate change policy in Scotland.

- **Transport –** This is a growing source of GHG emissions in Scotland. Setting fuel excise duty and vehicle tax is a reserved matter, thus the Scottish Parliament could not use this policy option to reduce emissions in Scotland. There is some concern that fuel taxes are thought to impact more on poorer households as they spend a higher proportion of their income on energy. The impact will vary, however, depending on car ownership and the location of the household (rural vs. urban). There are a number of different transport initiatives but that which has the lowest re-distributional effect is associated with increasing fuel duties and using the money to increase welfare payments. Increased use of public transport should also be considered.

- **Renewable energy –** Energy supply is the largest single source of GHG emissions in Scotland. Electricity is the major element of energy consumption and different generation sources have highly variable impacts on GHG emissions – more coal in the mix pushes emissions up, more nuclear pulls them down. Promoting the expansion of renewable energy is a major element of the Scottish Government's strategy on climate change. A new target has been set that by 2020 40% of electricity consumed in Scotland should come from renewable sources. Growth in, especially, on-shore wind power has been substantial in recent years, brought about largely by the complex and extensive government intervention in the electricity market. This includes the Renewables Obligation system and the Renewable Obligation Credits (ROCs) that flow from it. The additional costs of supplying energy from renewables as compared with the cheapest source are passed on entirely to electricity consumers, who thus pay for renewable energy expansion through higher bills. In Scotland, the cost of reducing one additional tonne of CO_2 from investing in (1) new onshore wind and (2) new offshore wind where the displaced power source is (a) coal and (b) gas was calculated. The results are shown in Table 4. It was found that each extra tonne of CO_2 emissions reduced from investing in onshore or offshore wind cost about £24 and £49 respectively if coal is the displaced source. This is very expensive compared with the EU-ETS price of carbon permits (£14/tonne at the end of September). For displacement of gas, costs per tonne of CO_2 reduced are £11 - £21 per tonne, which could make economic sense.

- **Agriculture –** This is a major source and sink of GHGs in Scotland. The main options for GHG mitigation in Scottish agriculture arise from improved cropland management, improved grazing land management and restoration of cultivated organic soils. The technical GHG mitigation potential of Scottish agriculture (in 2030) is estimated to be 4.0Mt CO_2eq. yr^{-1}. At low carbon prices, the combined mitigation potential of relatively inexpensive options for cropland and grazing management is similar to that of organic soil restoration, but as the price of carbon rises, the mitigation potential of the more expensive organic soil restoration becomes much greater, since a rising carbon price makes increasingly expensive agricultural mitigation measures become cost effective. A price of £10 per tonne of CO2 reduced would produce a significant amount of mitigation from Scottish farmers.

- **Forestry –** The forestry sector is a major player in net carbon emissions and likely to become more so over time. Currently, Scotland is a net sink for carbon, the size of which has increased by 61% between 1990 and 2003, primarily through forest growth. Planting new forests to lock up carbon dioxide has become of increasing interest to academics and the forestry sector. Forests absorb carbon as they grow, and can reduce the requirement to lower emissions from other sources over a variable time period. Clean Development Mechanism deals under Kyoto could, in the future, include forest planting and private companies are already buying and selling carbon sequestration in UK forests. Within Scotland, the Forestry Commission has publicised the basic analytics of carbon storage, whilst private brokers are emerging who will sell carbon storage in forests to a wide range of clients. However, the emergence of an 'official' market in carbon credits in forestry would depend on the EU allowing new sequestration to offset emission reduction requirements, so that carbon credits from forests could trade alongside CDM and EU-ETS credits.

- Given that Scotland is a very small player in terms of global emissions, it could be argued that scarce resources would be better devoted to **adaptation** (reducing future damages) rather than mitigation (reducing emissions) since costly Scottish emissions reductions will only have a tiny role to play in reducing the stock of global GHGs, whilst the benefits of adaptation accrue entirely to Scotland. Adaptation policy could involve: actions that reduce the impacts of climate change e.g. investing in flood defences, actions that pool or transfer the risk of change (insurance), actions that enhance the effectiveness of adaptation e.g. markets in the effects of climate change (catastrophe bonds). The economic principle to be used in all cases is that adaptation actions should be undertaken so long as the reduction in expected costs exceeds the costs of the actions taken. This could mean investing in better flood management systems so long as the costs are less than the value of expected damages from flooding over time, discounted to the present. We therefore need to know what impacts on the economy climate change is expected to have, to think sensibly about such actions.

- By the end of this century Scotland will have warmer, wetter winters, less snowfall and an increased risk of flooding. Some species of birds will disappear and freshwater salmon and sea trout may be affected by changing ocean circulation. The transport sector will be affected by flooding risks, storms and sea level. Increased inland and coastal flooding and higher energy requirements for cooling manufacturing processes will be further negative results of climate change. However, a faster mean wind speed will benefit wind and wave power schemes and energy consumption may fall as a consequence of higher winter temperatures. Tourism will benefit from warmer summers. The importance of adaptation policy lies in the response by all sectors to the range of anticipated climate changes. Governments have a role to play since they can alter institutions to make the system more resilient, but it is not desirable for public spending on risk reductions to crowd out private spending.

- **In conclusion**, Table 7 provides a summary of costs of reducing GHG emissions from different sources in Scotland. Several sectors could make a low cost (or, in the case of households, a negative cost) contribution to emissions reductions, including industry and agriculture.

- Climate change poses challenges to business in terms of adapting to new situations and new policy initiatives, but also offers opportunities, e.g. the development of Carbon Capture and Storage technologies, which could become profitable under the UK climate change programme. However, given the small contribution Scotland can make to reducing global emissions, is adaptation a more realistic response so long as the benefits of mitigation measures exceed the costs? This kind of calculation is difficult since it is hard to predict future climate change, its implications for economic and environmental systems and the human response to it. Importantly though, Scotland has established targets for cuts in GHG emissions and given that this is the case, this paper shows that economic analysis can make a valuable contribution to understanding what constitutes a ‘best response’ to these targets.

1. Introduction

This paper tries to summarise the insights that economic analysis can provide to answer a question of growing importance: *How should Scotland respond to the issue of global climate change?* This will involve us thinking about a series of questions:

- How should Scotland respond to targets which are set by EU and UK-level agreements, in terms of how it tries to achieve these targets?
- What threats and opportunities does climate change policy pose for Scottish business sectors?
- What should be the balance struck between reducing emissions of greenhouse gases (such as water vapour, CO_2, methane, and nitrous oxide) and taking actions to reduce future impacts?
- With regards to emissions reductions, how should they be allocated across the various sectors responsible for emissions, and over time?
- How will our actions today effect our options in the future?
- And finally, what actions does it make sense for Scotland to undertake on its own?

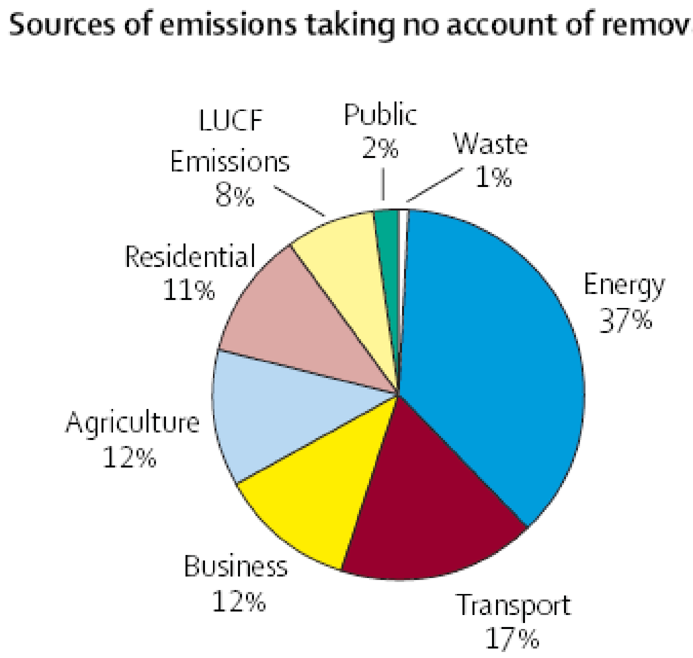
The paper does not discuss the science behind climate change, and by and large we take as given that targets currently exist for reducing Green House Gases (GHGs) which the UK, Scotland and the EU are committed to meet. Before reviewing how economics can help us think about the above issues, however, it is useful to give a quick overview of how Scotland is contributing to the climate change problem, in terms of emissions and targets, and what policies are currently in place.

2. Current Sources, Trends and Targets for GHGs in Scotland

2.1 Sources of greenhouse gases in Scotland

Scotland emits around 0.2% of total global GHG emissions, and accounts for 0.1% of the global population. As we show below (Figure 1), the largest source of GHG emissions in Scotland is the energy supply sector, producing 37% of all emissions. Most of this is due to electricity generation and oil refining. Business and industrial sources outwith energy supply account for 12.3%. Households directly produce a significant share of emissions (11%) as does agriculture, despite its small contributions to GDP. “Removals” account for 16% of emissions by absorbing them in carbon sinks such as growing forests: of 17.6 MtC total emissions in 2003, 2.75 MtC (16%) were removed by land use change and forestry, with growth in forest biomass accounting for most of these removals. Compared to the UK as a whole, energy supply is a bigger proportionate source of emissions in Scotland, and transport a smaller share. Carbon Dioxide accounts for the largest single contribution of individual GHGs to total Scottish emissions, as shown below (Figure 2):

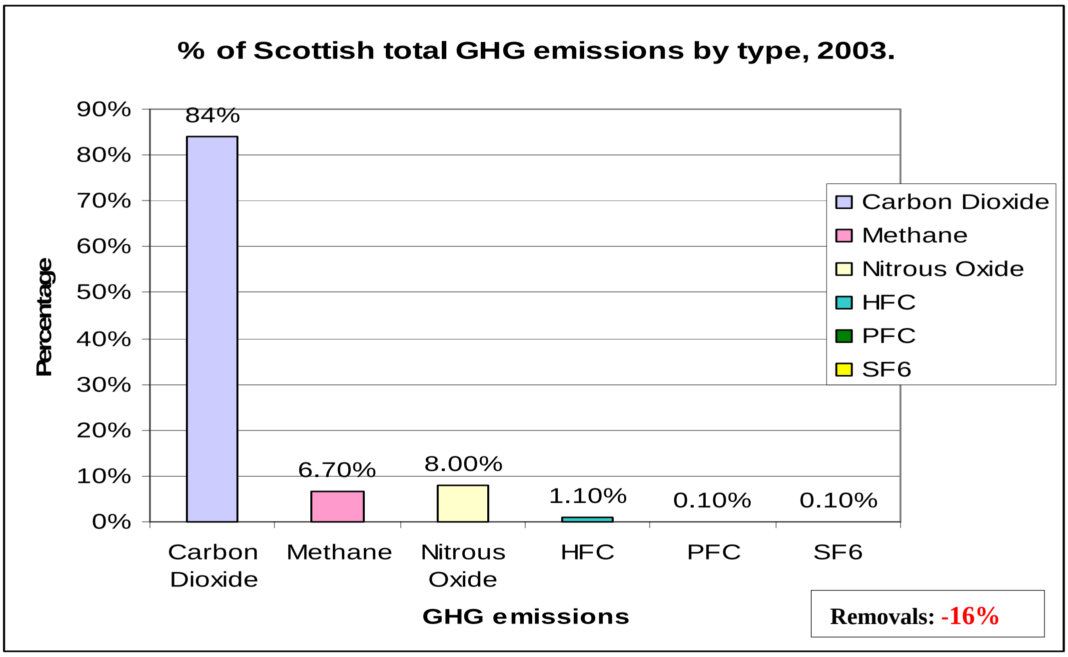
Figure 1



Removals: -16%

Source: Scottish Executive, Changing our ways: Scotland’s Climate Change Programme, 2006.

Figure 2



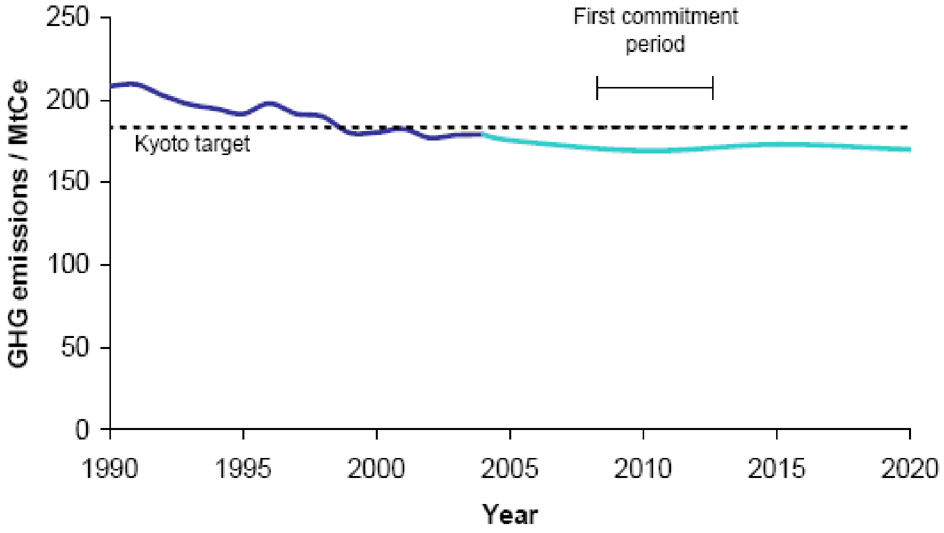
Removals: -16%

Source: Scottish Executive, Changing our ways: Scotland’s Climate Change Programme, 2006. HFC: hydroflurocarbons. PFC: perflourocarbons. SF6: sulphur hexafluoride.

2.2 Trends

Two kinds of trend are important to consider: trends by individual sources, and trends in total emissions. Overall, UK emissions have been falling since 1990, as Figure 3 below shows. This fall in CO2 emissions has partly been brought about by the government's climate change policy. However, much of the fall has occurred due to other factors, such as changes in the relative price of energy sources, and re-structuring of the economy.

Figure 3: UK progress towards meeting Kyoto Commitment

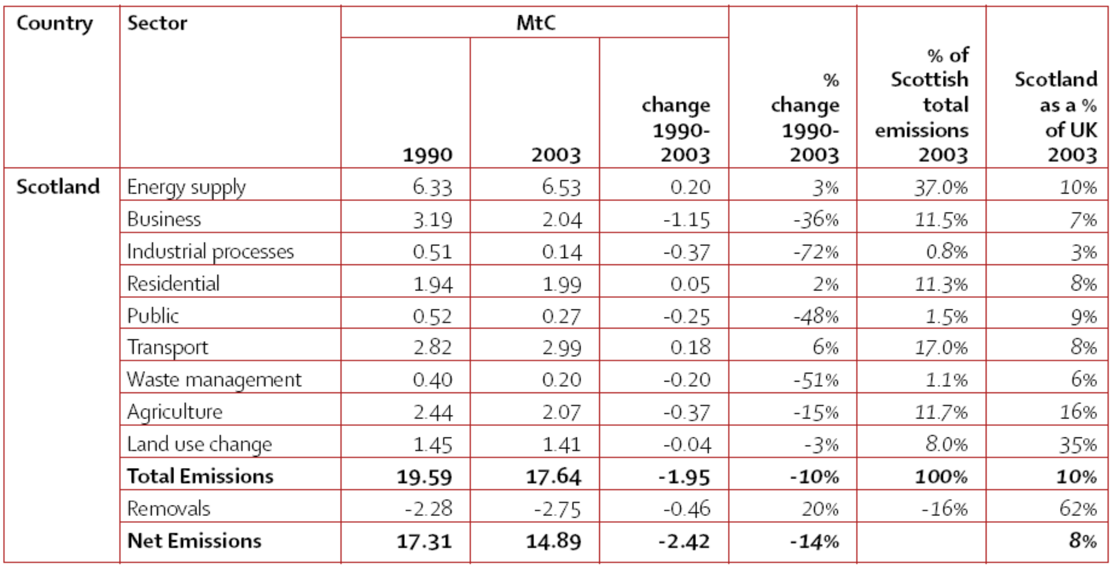


Source: Defra, The United Kingdom's Report on Demonstrable Progress under the Kyoto Protocol, 2006.

For Scotland, net GHG emissions (minus removal by forests and soils) fell by 14% between 1990 and 2003 (from 17.3 to 14.9 MtC) (Scottish Executive, 2006). In terms of comparisons with other EU Member States, Scotland's net GHG emissions reduction between 1990 and 2003 was greater than all others except Germany and the UK as a whole.

We now turn to trends in individual sources of GHG emissions. Comparing 2005 with 1990, transport's share of total emissions has risen whilst industrial emissions have fallen. Table 1 gives details: the large contribution of Scottish forests and land use change to total UK removals can also be seen here:

Table 1: Greenhouse Gas Emissions in Scotland.



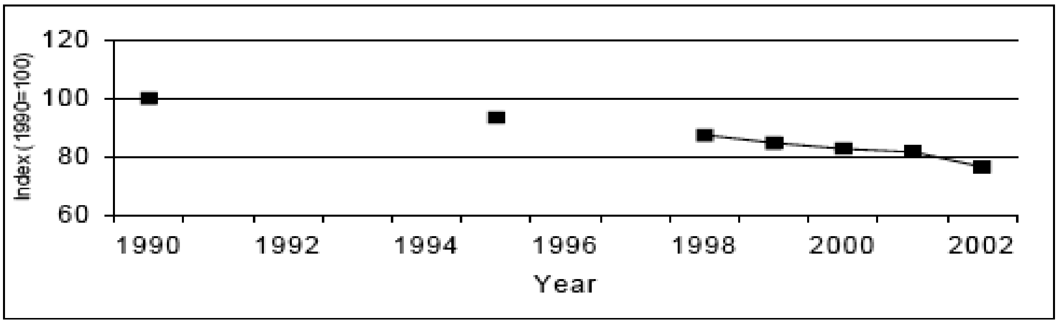
Country	Sector	MtC 1990	MtC 2003	MtC change 1990-2003	% change 1990-2003	% of Scottish total emissions 2003	Scotland as a % of UK 2003
Scotland	Energy supply	6.33	6.53	0.20	3%	37.0%	10%
	Business	3.19	2.04	-1.15	-36%	11.5%	7%
	Industrial processes	0.51	0.14	-0.37	-72%	0.8%	3%
	Residential	1.94	1.99	0.05	2%	11.3%	8%
	Public	0.52	0.27	-0.25	-48%	1.5%	9%
	Transport	2.82	2.99	0.18	6%	17.0%	8%
	Waste management	0.40	0.20	-0.20	-51%	1.1%	6%
	Agriculture	2.44	2.07	-0.37	-15%	11.7%	16%
	Land use change	1.45	1.41	-0.04	-3%	8.0%	35%
	Total Emissions	**19.59**	**17.64**	**-1.95**	**-10%**	**100%**	**10%**
	Removals	-2.28	-2.75	-0.46	20%	-16%	62%
	Net Emissions	**17.31**	**14.89**	**-2.42**	**-14%**		**8%**

Source: Scottish Executive, Changing our ways: Scotland's Climate Change Programme, 2006.

Governments are often interested in the degree to which GHG emissions and economic growth can be de-linked, for example by changing industrial structure, or improving energy efficiency. In Scotland, the "Sustainable Prosperity" indicator has been used to investigate whether this de-linking is occurring. Some results are shown in Figure 4: as can be seen, the pollution intensity of economic activity has fallen.

Figure 4

Index of carbon dioxide emissions divided by GDP (1990=100)

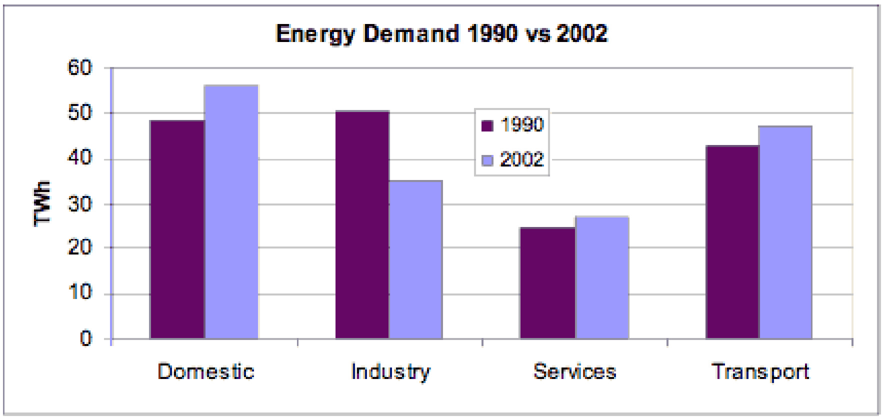


Year	1990	1995	1998	1999	2000	2001	2002
Index of carbon dioxide emissions divided by GDP	100	93	87	85	83	82	76

Source: Scottish Executive and NETCEN

Since CO_2 emissions are closely related to energy consumption, it is also interesting to look at national trends in energy use. Figure 5 from the 2006 Scottish Energy Study shows that, comparing 1990 with 2002, energy demand for the domestic, service, and transport sectors have all risen, whilst energy demand from industry has fallen. For example, domestic consumption rose by 15% over this 12 year period, from 48.5 to 56 TWh, whilst within this electricity demand rose 25%. Industrial use fell 31% over the period, partly a result of plant closures and partly from a change in the fuel mix away from coal and oil. Service sector energy demand rose 10% over the period.

Figure 5



Source: Scottish Energy Study, 2006.

2.3 Targets and Current Policies

The UK faces a target set under the Kyoto Protocol to reduce its emissions of CO_2 equivalents by 12.5% over the period 2008- 2012, relative to 1990 levels. The “Scottish share” of this cut is around 1.7 million tonnes in annual savings by 2010 (Scottish Executive, 2006). The Executive has stated that it wishes to exceed this target by 1 MtC, implying a total target of 2.7 MtC. Furthermore, the 2003 Energy White Paper sets a UK target of a 60% cut in emissions by 2050. Targets also exist for renewable energy supply as part of climate change policy - these are explained in section 4.

Current policy on climate change at the UK and EU level includes the EU carbon trading scheme outlined below, Climate Change Agreements, the Climate Change Levy on industrial use of energy, and energy policy targets and measures (section 4). The UK government’s Energy Review of October 2006 stated that the price of carbon should be included in all economic decisions, a point also made by the Stern Review, and Defra has just published a consultation paper on the value of this “shadow price” of carbon. This suggests a value of £25 per tonne CO_2 equivalent in 2007, rising over time to £59 in 2050.

EU technology-forcing emission and energy use standards for cars, vans and lorries are also relevant, as is the EU Directive on Biofuels. In Scotland, the Carbon Trust and the Energy Saving Trust fund and promote investments in domestic energy efficiency. The Scottish Energy Efficiency Strategy promotes energy efficiency in the non-domestic sector.

Building standards are increasing energy efficiency in new housing and commercial developments, whilst interest free loans are available for energy saving investments in the public sector.

3. Some basis principles in the economics of pollution control

In this section, I review the contribution that economics can make to thinking about how best to cut GHG emissions. The overall thrust of this section will be to suggest that, if Scotland wants to hit its targets for cutting GHG emissions at the lowest cost to the economy, then policies need to be adopted which:

- Put a price on pollution and a value on pollution reduction;
- allow the lowest cost options for cutting emissions to be realised first;
- allow flexibility of response across firms, and thus recognise that emissions reductions come at very different costs across polluters;
- are capable of equalising the additional costs of reducing pollution across sectors. This, as we will argue, should be a crucial guiding principle of an economically-rational national plan for responding to the climate change challenge.

3.1 The concept of abatement costs and the least-cost principle

The economic theory of pollution control revolves around the idea of cost-minimisation. Ignoring for the purposes of this paper the notion that society could identify an optimal level of pollution reduction – since this would involve us knowing everything about the costs and benefits of pollution control over time – we focus instead on the idea of hitting some pre-determined target at lowest social cost. These social costs can be thought of in terms of *abatement costs*: the costs of reducing pollution. In general, abatement costs can relate to (i) the costs of using cleaner inputs in production (e.g. swopping a lower carbon content fuel for a higher carbon content fuel); (ii) installing and operating pollution abatement equipment (e.g. installing a scrubber in a smoke stack to reduce SO_2 emissions); (iii) the costs of reducing output. For greenhouse gases, examples of abatement costs for industry are:

- Investing in energy-saving technology
- Switching to lower C-content fuels for production, heating and transportation from higher C-content fuels
- Reducing output
- For farmers, reducing their stocking levels to reduce methane emissions
- For airlines or bus operators, replacing their fleet with more fuel-efficient planes or buses.

For households, abatement could come about by:

- Investing in energy saving, such as cavity wall insulation, or buying a more energy-efficient car
- Changing consumption patterns e.g. taking less foreign holidays by plane, moving to a smaller house
- Changing travel-to-work mode

For an economy as a whole, abatement of GHGs could also occur by a change in the mix of outputs (e.g. a reduction in production of energy intensive outputs, and an increase in less energy-intensive outputs); a change in its energy production mix (e.g. a switch from coal power to nuclear power), or by investing in carbon capture by forest planting or some other means.

Whilst some of these actions might generate net cost savings over time (for example, investing in energy saving measures), we may assume that at least some of these actions are costly. The claim that many of these actions can be taken at a negative cost raises the question as to why firms or households do not already undertake them – with the only economic explanations being ignorance, transactions costs or capital constraints. *However, for the rest of this section we will assume that actions by either firms or households to reduce GHG emissions are costly.*

What can we say about the nature of these pollution abatement costs? Let us focus on industrial sources for the moment. Figure 1 in the Annex shows a marginal abatement cost, or MAC, for a typical firm. As emissions are reduced (moving us from right to left along the horizontal axis), the incremental costs of achieving these reductions rises. In other words, pollution control gets increasingly expensive "at the margin" as a firm progressively cleans up its act. In developing our arguments, we now need to make a couple of assumptions. These are that (i) firms will always choose the lowest cost option in reducing pollution; and that (ii) marginal abatement costs vary significantly across firms. The first of these seems reasonable (why would firms not choose the cheapest option?), whilst the latter is borne out by much empirical research (e.g. Hanley and Moffatt, 1993). Based on this, the fundamental result on the economics of pollution control can now be stated:

The social costs of reducing pollution will be minimised when marginal abatement costs are equalised across polluters.

This result, which is due to Baumol and Oates (1975), can be illustrated in Figure 2 (presented in the Annex), where the marginal abatement costs for two different firms are shown. We can see that Firm A finds it more expensive to reduce pollution than Firm B. Forcing each firm to cut pollution by the same amount – for example, to E_r - means that the MACs for the two firms are not equalised: cutting the last unit of pollution costs A £50/ton but only costs B £30/ton.

This means that costs could be saved by requiring A to do less pollution control and B to do more. These potential costs savings exist so long as the MACs of the two firms remain different.

On the other hand, if somehow firm A can be encouraged or forced to reduce emissions to E_a and firm B to E_b then it can be seen that the MAC for both firms equals £40/ton. Now no more costs can be saved by re-allocating pollution reduction across the two firms. Notice that now the firm who finds it relatively cheap to reduce emissions cuts pollution by more than the firm that finds it more expensive. From society's point of view, this *cost-minimising* outcome is very desirable. But how could it be achieved in practice?

Clearly one obvious option is for the government, or environmental regulator, to simply tell firms how much to cut emissions. But in order to minimise social costs, this requires the government to know the marginal abatement costs of every polluter. Given how many industrial sources of greenhouse gases there are in the UK, this is an impossibly large information requirement. In any case, marginal abatement cost curves can be expected to vary over time, for example as energy prices or interest rates change. It is thus unrealistic to think of the government imposing a least-cost solution. *The government can and does impose regulations on pollution control – indeed, this "command and control" approach to environmental regulation is by far the main way in which pollution is regulated. But this will not be economically efficient at all.*

3.2 Economic instruments, regulation and voluntary approaches

Dating from the early 1970s, economists have maintained that setting a tax on pollution, or issuing tradeable pollution permits, can bring about the cost-minimising outcome shown in Figure 2 in the Annex (Hanley et al, 2007). Pollution taxes and tradeable permits are two types of policy known as "economic instruments" or "market mechanisms", and their attractiveness to economists is based on the flexibility that they allow for in terms of polluters' responses, and on *the way in which they align private motives with public gain*. Let us consider how in general a pollution tax, and then a tradeable pollution permit market, works, and then make some comments more specific to cutting greenhouse gas emissions.

Suppose that the firm shown in Figure 1 now faces a tax on its CO_2 emissions. For each ton of pollutant emitted, the firm must pay £30. How would a firm respond? The answer is shown in Figure 3 in the Annex. The firm would cut its pre-tax emission level of E_f to E_t where the tax rate is just equal to the MAC curve. Why? Because this is the cost-minimising reaction for the firm. At any point to the left of E_t the extra costs of cutting emissions are bigger than the per-ton tax, so the firm would want to cut pollution by less. At any point to the right of E_t , the marginal costs of cutting emissions are less than tax, so the firm would want to cut pollution more. Only at E_t do no more options exist for cutting costs. Notice that the firm now pays two kinds of cost – tax payments to the government shown by the shaded area, and pollution control costs.

Tradeable permit markets can, in principle, achieve the same cost-minimising outcome as pollution taxes. Indeed, this is the belief that lies behind the EU Carbon Trading scheme discussed below. Imagine that the firm shown in Figure 1 no longer has to pay a carbon tax, but now has to hold enough permits to authorise its emissions. That is, if each permit allows the emission of one ton of CO_2 per year, and the firm emits 100 tons, then it needs to hold 100 permits.

Permits can be bought and sold in the market: firms that do not hold enough can buy, firms that hold too many can sell. The total supply of pollution permits is fixed by the government. Interaction of supply and demand then sets the price that permits trade at. Each firm considers this price and decides how many permits to hold. In Figure 4 (in the Annex), our firm sees that the price of carbon permits is P*. Given this, it will choose to hold E* permits, which means cutting emissions to E*.

The argument for why this is the firm's best response is identical to that for the tax above: below E*, the marginal costs of cutting emissions exceed the permit price, so it is cheaper to hold permits than to cut emissions. Above E* the permit price exceeds the marginal costs of cutting emissions, so it is cheaper for the firm to cut emissions than to buy permits. If the firm has been given E_a permits at the start of the scheme (see the discussion below for more on this), then this means it will need to buy $(E^* - E_a)$ permits from the market to reach its desired holding.

The advantage of both economic instruments, pollution taxes and tradeable pollution permits, is thus that the cost-minimising pattern of pollution control is achieved in a de-centralised manner, by firms choosing their own best response to either the tax or the permit market. Society thus gets its pollution reduction for a lower price than would be the case under command-and –control. Paradoxically, for the individual firm, costs might be greater under a tax scheme than under regulation, since the firm pays both its abatement costs and its pollution taxes (under a tradable permit scheme this is only true if all the permits are auctioned). This financial impact of the tax goes some way to explaining the resistance to pollution taxes in both the EU and USA over time. Pollution taxes face other problems too, some of which are taken up in section 3, such as the impact on poor households in the case of energy taxes, or impacts on international competitiveness. But it is certainly the case that the government could choose to offset these impacts, for example by reducing other taxes, such as labour taxes (sometimes known as a "double dividend"), or even aiming for a revenue-neutral policy.

Two potential complications need to be addressed before moving on. First, one simplifying assumption behind the "standard" least-cost tax and tradeable permit theory is that the pollutant that is being so regulated is "uniformly mixed". This means that the damage done by a ton of emissions does not vary systematically with the location of discharge. This is clearly *not* true for many pollutants. For example, in regulating sulphur dioxide emissions in order to reduce acidification of lakes, or in regulating diffuse pollution from farmland run-off, the spatial location of discharges is a very important determinant of the impacts of pollution. This complicates the design of pollution taxes and tradeable pollution permit markets considerably. But, fortunately, greenhouse gas emissions do not suffer from this problem, since the contribution of one ton of CO_2 to climate change does not depend on where on the planet this ton of CO_2 is emitted.
Since this is the case, taxes and tradeable permits can be specified in terms of emissions rather than spatially-varying impacts. This greatly simplifies the design of pollution taxes and tradeable permits.

It is true that the different greenhouse gases vary in terms of their global warming potential and decay rate in the atmosphere. For example, each molecule of CH_4 has a warming potential 21 times greater than each molecule of CO_2, but has a decay rate in the atmosphere which is 10 times faster (Moffatt, 2004). In principle, a "greenhouse gas tax" levied on any of the main GHGs could easily be adjusted to allow for these differences.

The second complication with a cost-effective strategy for the control of GHGs is the dynamic nature of the climate change problem. Climate "forcing" is not a function of this year's emissions of GHGs, but rather of the cumulative stock of GHGs in the atmosphere. Many of the GHGs have long residence times in the atmosphere, for example CO_2 has a lifetime of 120 years, and N_20 has a lifetime of 150 years. This means that most of the current warming of the earth is due to historic, rather than current-period, emissions. Moreover, current emissions will contribute to warming for many years into the future (Arrow, 2007). The stock of GHGs in the atmosphere is about 430 parts per million (ppm) today, compared with a pre-industrial level of around 280 ppm. Predictions are that the stock could reach 550 ppm by 2035 (Arrow, op cit).

For a stock pollutant like GHGs, the cost-minimising pattern of abatement must also take into account the passing of time. As Nordhaus (2007) argues, a standard result from dynamic optimisation is that the carbon tax should grow over time at the "carbon interest rate": this is equal to the market (real) interest rate minus the rate of disappearance of CO_2 from the atmosphere. The Stern Review also argues that the shadow price should rise over time since one more tonne of GHGs emitted when the stock is higher does more damage than the same tonne of emissions when the stock is lower.

As we have seen above, both a carbon tax and a tradeable permit system could, in principle, achieve a given reduction in GHG emissions at lowest cost to society – and certainly a lower cost than would be associated with a purely regulatory approach. However, can we say anything about whether a carbon tax would be better than a tradeable permit system? Or should a mixed system be preferred?

3.2.1 Are carbon taxes better than tradeable carbon permits?

One clear advantage that carbon taxes have is that, so long as they are levied high enough up in the supply chain, they send signals to all activities that emit carbon, no matter what the size of the polluter. We noted above that the residential and transport sectors are significant sources of GHG emissions in Scotland. It is interesting that the EU carbon market has so far only targeted large industrial sources of emissions, since these are easier to monitor in terms of compliance. But how could we use a tradable permit market to regulate emissions from home heating systems across Scotland, or for cars and motorcycles? This would involve monitoring emissions from all these sources and comparing them to permit holdings, a large task indeed.

Yet a tax on the carbon content of fuels would send the correct "carbon signal" to all these millions of polluters, whilst levying the carbon tax high enough up the supply chain would make it relatively easy to administer. Even products and services made with energy inputs would embody the carbon price in their prices.

One issue for quantity-based schemes such as tradeable permits is that a baseline must be agreed and set. Baselines are important since they determine the quantity of permits allocated: for example, if the target reduction in GHG emissions is “20%”, then this only makes sense if we know what the reference point is : 20% of historical emission levels? 20% below what emissions would be in the future with no permit system in place? Baselines also matter for the initial allocation of permits, since this has typically been based on firms’ historical emission levels. Yet this may penalise firms who have engaged in more past emission control, which sets up an incentive problem for future allocations (MacKenzie et al, 2007). Setting baselines is even more problematic for international permit trading, as the EU National Allocation Plan process has shown.

Uncertainty is a key feature of the climate change debate. Economists have worked for some time on the issue of whether pollution taxes or tradeable permits are better when there is uncertainty over the costs and benefits of pollution control. The answer turns out to depend on the shape of the benefit and cost functions. When costs are non-linear and benefits are linear, then taxes do better (in expected value terms) than tradeable permits. The intuition is that taxes do a better job of ensuring cost minimisation, whereas permits do a better job of ensuring targets are met. As we noted above, climate change is a stock pollution problem. Climate change impacts (and thus the benefit of pollution control) depend on changes in the stock of GHGs, which changes only slowly. Costs of abatement however depend on current emissions. Since costs are therefore more sensitive to current emission levels than benefits, uncertainty suggests that a carbon tax should be associated with lower expected losses (higher expected benefits) than a tradeable carbon permit system (Nordhaus, 2007; Hoel and Karp, 2001).

Environmental taxes also raise money for the government, and may be designed with fiscal neutrality in mind. The “double dividend” effect arises when a pollution tax allows a fall in pollution and a rise in revenue, but also provides governments with the option to reduce other taxes. If the taxes reduced are distortionary, such as labour taxes, then a secondary benefit arises in the form of reduced deadweight losses in the labour market (Goulder, 1995). The government has thus partly replaced a tax on a “good” (labour supply) with a tax on a “bad” (pollution). David Cameron has recently stated that shifting the tax burden partly from labour to environmental bads would be a guiding principal of a future Tory administration (The Times, 10/09/07). The UK government’s Climate Change Levy is an energy tax the fiscal effect of which is meant to be offset by reductions in labour taxes paid by firms[1]. In Sweden, the government funded a tax cut to low- and middle-income families by increasing environmental taxes over the period 2001-2004.

However, the net effect of tax offsets is case-dependent, and may result in a loss of welfare if one considers the effects of the carbon tax on consumer prices and thus on real wages (Parry, 1995; Parry, 2003). Moreover, whilst budget-balancing may be undertaken at the level of a sector or of industry as a whole, some individual firms will gain and some will loose, depending on their input mixes (e.g. compare more energy intensive firms with more labour intensive firms).

---

[1] Some of the funds raised are also used to finance schemes aimed at energy efficiency improvements through the carbon trust. This was also the pattern of revenue recycling in Germany and Denmark.

Finally, we might expect that the nature of tradeable permit markets for pollution is a volatile one. Carbon permit prices could be expected to be volatile since supply is completely fixed, whilst demand is rather inelastic, since substitution away from carbon-intensive fuels is difficult in the short run. Nordhaus (2007) points to the high degree of volatility in sulphur emission trading prices in the US, which have been as volatile as oil prices. Regulatory announcements, such as the market over-supply situation in spring 2006, caused big falls in the EU carbon price (Convery and Redmond, 2007). Volatility of such a vital input – carbon – to modern economies is argued to be undesirable, although the developing of banking and borrowing for carbon credits in the future would moderate this volatility.

3.2.2 Are tradeable carbon permits better than taxes?

One major political argument deployed against environmental taxes in general, and carbon taxes in particular, has been their alleged effect on competitiveness. The European Union, for example, decided against introducing a carbon tax partly on the grounds that this would impose a cost penalty on European firms seeking to compete on world markets. Partly in recognition of these predicted effects, industries which were heavy users of energy were largely exempted from the UK Climate Change Levy in return for "voluntary" agreements on emissions reductions. The competitiveness argument was also behind the reduction in employers' NI contributions which accompanied the Levy. Whilst taxes might be least-cost to society as a whole, they might increase the financial burden of regulation on individual firms relative to a pure regulation (command and control) situation.

However, what evidence is there that environmental taxes harm competitiveness to a significant degree? Ekins and Speck (2007) look at the effects of energy taxes on competitiveness in six EU countries over the period 1990-2006[2]. They note that a decrease in the labour-taxation-to-GDP ratio, and an increase in the environmental taxation-to-GDP ratio occurred in Denmark, Finland, Germany and the Netherlands. Focussing on three energy-intensive industries (basic chemicals, cement, and ferrous metals), the authors find that energy taxes only have a small effect on the price of energy inputs to the three industries studied, and that there are big differences in the ex-tax price of energy across the six countries studied. They conclude that "*..concern with the competitiveness effects of energy taxes may have been excessive*". Environmental taxes also encourage innovation in cleaner technology, since this reduces tax payments per unit of output; any undesirable effects on competitiveness might thus fall over time.

Another potential problem for the carbon tax approach to environmental management is that governments do not start with a "clean slate" – we already tax/subsidise energy and carbon use in many countries. For example, transport fuels are heavily taxed in the UK; whilst coal production may be subsidised in other countries. Electricity prices may be regulated by the state.

---

[2] Note that the cases they consider are where energy taxes were introduced alongside reductions in other taxes, as with the Climate Change Levy.

What this means is that setting the correct carbon tax – that is, the rate that assuming no other taxation or subsidy schemes in place would allow us to achieve a target reduction in GHG emissions – is complicated. Governments would either have to remove existing energy tax/subsidies before introducing the carbon tax, or else calculate the correct new “net” carbon tax. However, this net tax rate might vary across sectors. Indeed, Nordhaus (2007) has argued that in terms of setting a *global* carbon tax, the net tax rate for EU countries might be zero, since we already tax fuels (especially for transport) at a globally high level.

One worry about a wider use of environmental taxes is their distributional effects, especially their impacts on lower income groups. This was one official reason for exempting domestic energy use and transport from the Climate Change Levy. Environmental taxes send signals to consumers by making consumption of environmental resources more expensive. However, there are concerns that their effect could be 'regressive', by hitting lower income households disproportionately. Research by Dresner and Ekins (2004) investigated their possible impact on low-income households in four areas: domestic use of energy, water and transport, and domestic generation of waste.

They also considered whether any negative impacts could be reduced if the tax or charge were designed appropriately, or if a compensation scheme were introduced. The study found that low-income households' use of energy, water and waste disposal services, and their use of cars where they own them, is disproportionate in relation to their income. This confirms that a flat-rate tax or charge applied to such usage would be regressive. For the average low-income household, the disproportionate impact could be removed through an appropriate (i.e. non-flat rate) design of the tax or charge scheme and/or by introducing a compensation scheme along with the tax or charge – although this would clearly have transactions costs associated with it, and could produce knock-on incentive effects. However, use of environmental resources tends to vary widely within a given income group (e.g. between rural and urban households). This means that, in practice, some low-income households would end up as net losers from any charging-plus-compensation scheme, even when the scheme leaves low-income households better off on average. More detail is given on the authors’ findings for transport in section 4.

Economists would, of course, assert that the distributional impacts of green taxation should be tackled independently of the desire to reduce emissions in a cost-effective manner, since fairness and efficiency are two separate objectives of government policy which need separate policies in place to deal with them. Yet this neglects the political economy of policy choice – distributional impacts are fundamental to the acceptability of policy options. A good illustration of this fact is that worries over the political acceptability of rising fuel prices, sparked by civil unrest, caused a major U-turn in recent government policy on green taxation. The rising world price of oil and consequent fuel protests led the government to abandon the fuel duty escalator which had been put in place specifically to send a signal to fuel users to reduce consumption and thus emissions.

Finally, it should be noted that one major difference between pollution taxes and tradeable permits is the degree of certainty over whether a GHG reduction target would be achieved.

So long as the scheme is adequately monitored and enforced, then a tradeable permit system will not allow emissions beyond that aggregate level implicit in the total permit supply. For example if only a total of 6 million tonnes of carbon permits are issued to the energy sector, then so long as illegal emissions do not occur, the maximum emission level from that sector is 6 million tonnes. However, a carbon tax will only achieve this target if (i) the government has calculated the correct rate (for which it needs accurate information on marginal abatement costs for the sector) and if (ii) all firms in the sector respond in the cost-minimising way. Otherwise, the target may be over or under achieved.

3.3 Policy choice and technological change

Early economic analysis of pollution problems treated technological change as an "external event" which was not determined by policy choice. But economists now see technological progress as endogenous, in the sense that the government's choices over what policy instruments it introduces to regulate pollution (a tax, a tradeable permit system..) has an impact on the speed and nature of R&D activity, and the take-up of new technologies. For example, a pollution tax can be shown to produce greater incentives to innovate into a cleaner technology than command-and-control (Hanley et al, 2007).

Recognizing this relationship has important consequences for the assessment of policy options, particularly in the context of climate change where the costs of carbon abatement depend so much on technological options for abatement. Increased innovation reduces abatement costs and thus reduces the carbon tax needed to hit a given target. However, because it drives down abatement costs, induced innovation also makes a tougher target more desirable. To try to quantify these impacts, Popp (2004) adopts the Nordhaus DICE model of climate change economics to capture the effects of changes in energy prices – including any carbon tax – on innovation in the energy industry. He finds that ..”ignoring induced technological change overstates the (economic) costs of a carbon tax by 10%”.

Moreover, policy choice by governments has implications for business opportunities for early innovators in green technology. For instance, actions by the government in setting ambitious targets for renewable energy, and providing tax incentives to help firms achieve these in Denmark is often credited with helping to establish a competitive advantage for Danish firms producing wind turbines.

Indeed, a general principal known as the "Porter Hypothesis" states that countries can help domestic firms to develop a competitive edge compared to their international competitors by setting higher standards than their competitors, since this gives their firms a "first mover" advantage, and may also encourage greater efficiency by increasing the cost of environmentally-damaging inputs including energy. There are two reasons why Porter's hypothesis may be correct: first, tighter environmental regulations make firms aware of opportunities for changing production activities in ways not previously identified; second, firms subject to stricter environmental standards than their foreign competitors may be at a competitive advantage when environmental standards are tightened in their competitors markets. However, empirical support for this theory is somewhat patchy.

3.4 Do economic instruments actually work?

We argued above that, in theory, either a carbon tax or a tradeable carbon permits system could achieve a target level of GHG emission cuts for Scotland at the lowest cost to society. But what evidence is there to support this? Not much, in the case of GHGs: the European carbon trading system is very new (although see below for a brief overview of how it has worked), whilst no country has set a carbon tax high enough to achieve its Kyoto targets. Countries have imposed carbon taxes (e.g. Denmark and Finland) or energy taxes (many countries: see the review in Missfeldt and Huaff, 2004), but these have not been set high enough to achieve environmental targets on their own. Many are viewed as either revenue raising in primary motivation, or in terms of enforcing the Polluter Pays Principle.

However, there is evidence for other pollutants. One of the biggest experiments in pollution control came in the US in 1990, with the introduction of a "sulphur trading" programme to reduce SO_2 emissions from power stations by 50%. Sulphur permits are denominated in annual tons of emissions, and can be banked. Permit prices fell from $131to $95/ton during the first 5 years of trading, as the opportunity to trade in emissions helped lower abatement costs (Ellerman et al, 1999). While many trades have occurred, most have been internal rather than external, and high monitoring costs may have eroded the cost savings of the scheme. But the volume of trading has risen over the life of the scheme (e.g. from 130,000 sales in 1993 to 5.1 million in 1997), and large cost savings have still resulted, estimated by the General Accounting Office at $2 billion per year, and by Ellerman et al as between 1/3 to 1/2 of the cost without trading. This cost saving is partly due to the phenomenon whereby the existence of trading possibilities has reduced prices of pollution control equipment, while fuel switching is also allowed. Estimates suggest that the benefits of the scheme have been considerably in excess of the costs (Burtraw, 1999). We can thus point to good evidence of a tradeable permit scheme achieving actual cost savings in practice.

Economic instruments to control pollution are indeed being employed more widely across the globe. A report by the US National Centre for Environmental Economics (NCEE, 2004) reviews global experiences with economic instruments for managing the environment, including air and water quality, water quantity, solid and hazardous wastes. A comparison was drawn with a previous US EPA-funded survey in 1997. The main findings of the report were:

- **Direct fees and taxes** are the most used economic instruments internationally. Noteworthy trends include more applications and higher rates, as well as some acceptance in parts of the world where charges heretofore have been difficult to implement.

- **Pollution permit trading regimes** have gained greater acceptance worldwide. New applications of marketable permits for conventional pollutants in nations such as Chile, China and Slovakia are noted

- **Greenhouse gas emission control** is an important and rapidly growing application of economic instruments. In 1997 just a handful of nations imposed carbon taxes.

Now many more nations use carbon and energy taxes, and greenhouse gas trading regimes are in place.

3.5 The European Carbon Market

Under the terms of the Kyoto Protocol, the European Union agreed to reduce greenhouse gas emissions by 8% from 1990 levels by 2012. One mechanism used to reach this target is the establishment of the *European Union Emissions Trading Scheme* (EU-ETS) (European Commission, 2003). The program is implemented in two phases: the first period, 2005-2007, is being used as a `warm-up period' where firms can gain experience and knowledge of the emissions trading process (Zapfel, 2005) before the Kyoto Protocol comes into force in the second period from 2008-2012.

The European Commission restricted participation to just under 12,000 installations from four broad CO_2 energy-intensive industries:

- Energy Activities: Combustion installations with a thermal rating higher than 20 MW, mineral oil refineries and coke ovens
- Ferrous metals: production and processing of metal ore, pig iron or steel
- Minerals: Production of cement, glass and ceramic products
- Other activities: pulp paper and board production

Under this scheme, regulated firms, from all 25 member states, can freely trade allowances but must have, at the end of the compliance periods, enough permits to cover their own emissions (otherwise a penalty is imposed). Initially, every member state is responsible for establishing a National Allocation Plan (NAP) which identifies both the process of allocation and the total number of permits distributed to domestic firms (installations).[3]

Although each member state has a large amount of freedom within its national allocation choice, these decisions are guided by Commission criteria (see Annex III European Union, 2003). For example, the allocation process is restricted to methods that freely distribute 95 per cent and 90 per cent of the allowances in the 2005 and 2008 periods respectively – a firm limit is thus placed on the use of auctions. Each member state has to submit their NAP to the European Commission for approval and it must be consistent with the member state's Kyoto target whilst avoiding any discriminatory outcomes for sectors or companies; that is, the NAP must not cause competitive distortions within the EU. Around 6.5 billion allowances have been allocated to about 11,500 sources.

Likewise, under general guidance from the European Commission (EC, 2004), each member state is responsible for establishing accounting measures to monitor, report and verify emissions.

---

[3] To create the NAP each member state must first decide the division of their Kyoto commitment between the emissions market participants (trading sector) and the rest of their economy (the non-trading sector such as households, transport use etc). Once an overall target has been generated, the member states then have to create targets for each individual affected sector and create the distribution procedures for the permits (Kruger and Pizer, 2004).

Moreover, each member state must establish a national registry to log allowance transactions which will be overseen by a centralised administrator at the EU level (Convery and Redmond, 2007). Therefore a bilateral trade "involves communication between three different electronic data systems" (Kruger and Pizer, 2004). To increase flexibility and lower compliance costs, the EU-ETS can also be linked to other mechanisms under the Kyoto Protocol, such as Joint Implementation (JI) and Clean Development Mechanisms (CDM) which allow a greater variety of low compliance alternatives and improve liquidity in the market. This was permitted by a "Linking Directive". The effect of this has been to increase the liquidity of the European carbon market, and to put a downward pressure on allowance prices. EU ETS trading dominates, however: in 2006, 62% of all carbon trades registered by Point Carbon – a major private sector source of information on the carbon market - were for EU ETS, with 34% for CDM credits and 1% for JI credits (by volume). However, the percentage of non-EU ETS is likely to rise over time. Currently, China dominates the CDM market as a supplier of credits with around 70% of the market in 2006. JI credits largely originate in Eastern Europe, with the Czech Republic being the biggest single source in 2006.

Point Carbon (2007) note a fluctuation in quarterly trading intensity in 2006. Prices also fluctuated considerably over the period, determined partly by the weather (demand for electricity and hydropower production) and by fuel prices (particularly the relative price of coal and gas, since coal is more carbon intensive than gas). Redmond and Convery (2006) report analysis which shows fuel prices to be the most important carbon credit price driver over the period to end July 2006. Between July 2005 and April 2006 the price of permits traded over the 21-30 Euro per tonne of CO_2 range. But a large collapse in April/May 2006 was brought about by announcements of verified emissions data, which showed that the overall market was in an excess supply position (countries has issued more permits than were being used): prices fell from 30 Euro to less than 12 Euro per tonne. Interestingly, a survey of carbon market participants by Point carbon showed that "political factors" were indeed seen as being the most important long-run and short-run driver of prices, with CDM and JI supply and fuel prices also seen as being important.

It is obviously too soon for a full assessment of the effectiveness or the efficiency of the EU-ETS. Point Carbon (2007) note that in some sectors, the market has seen investments in energy efficiency and bio-fuel production, as emissions become more expensive: although there is no analysis available which shows cause and effect. Their survey shows that the "primary carbon compliance strategy" is internal abatement for around 25% of respondents, and trading within the EU ETS for 35% of respondents. Interestingly, both these categories of responses are higher in 2007 than in 2006. Just under 50% of firms believe that "the EU ETS is the most cost-efficient way to reduce emissions". The sensitivity of prices to external shocks (political announcements, for example) is proof of the general observations made by Nordhaus (2007) which we noted above. Convery and Redmond (2007) note that most market participants seem to support the scheme, albeit with some reservations.

Economists certainly applaud the emergence of a tangible "price for emissions", although environmentalists worry that this price is too low at present due to overly-generous initial allocations.

The Commission is signalling tighter allocations in the future, which will push the price of carbon permits upwards. Nevertheless, the ramifications of a real price for carbon reverberating throughout the EU's economies, and the flexibility which EUETS, CDM and JI trading presents polluters with, can only be good news for environmental economists.

4. Cost-effective control for Scotland by sector; or how *not* to reduce emissions

The main point that emerges from Section 3 is that a cost-effective control policy for GHG emissions is one which balances Marginal Abatement Costs (MAC) across sources. In this section, we try to compare MACs for a number of important emission sources within Scotland, although this exercise is severely hampered by the almost complete lack of research that has been done on this issue within Scotland. We also point up some of the other important likely impacts of choosing particular sectors of the economy for tighter emission controls. The sectors we consider are:

- Industry
- Housing
- Transport
- Renewable energy
- Agriculture
- Forestry

4.1 Industry

For those sectors of industry which are part of the EU ETS scheme, we can measure the marginal abatement costs for GHG emissions by considering the price of permits. The logic is that no firm will engage in costly emissions reduction if the cost per tonne exceeds the price of carbon permits.
For Scotland, 81 firms are currently covered by the EU ETS, split across the following sectors (Table 2): A further 21 firms are to be allocated permits in phase 2 of the ETS, which will mean that around 50% of Scottish CO_2 emissions are covered by the scheme (Scottish Executive, 2006).

Given the current permit price of 21 euro (£14) /tonne CO_2, we can say that from the perspective of a cost-effective distribution of emission control across Scottish sources, this represents the cost of increasing emission control in these sectors, since over time firms will rationally adjust their emissions to the point where their own MAC is equal to this permit price.

Marginal abatement costs will vary considerably across and within all sectors, including those not part of the EU ETS, but at present we have no information on the current distribution of these costs, nor on how they will change over time as (i) rules on carbon trading evolve (ii) future allocations are reduced and (iii) fossil fuel prices evolve and technologies change. But as a rough guess, we could use 21 euro (or £14) per tonne of CO_2 as the current price of cutting carbon emissions from Scottish industry.

Table 2: EU ETS permit allocations in Scotland

Aerospace	1
Brewing	1
Ceramics	4
Chemicals	12
Dairies	1
FDT	1
Food & Drink	1
Offshore	6
Other Oil & Gas	8
Power Stations	13
Pulp & Paper	4
Refineries	2
Services	30
Spirits	2
Wood Board	2
Total Phase 1	88

Source: SEPA

Another strategy that the government can and does engage in for reducing carbon emissions from industry is to persuade or incentivise industry to increase investments in energy-saving technology. Such options are often thought of as "win win", since firms can reduce their costs at the same time as emissions are cut. This rather then begs the question as to why firms would not voluntarily engage in any such investment in energy efficiency, since they could increase their profits by doing so. If this is so, then there is no need for governments to intervene.

However, suggestions have been made that firms (especially SMEs) may be unaware of these potential costs savings, or operate higher discount rates than society would choose; or we may simply want to bring about a higher level of energy saving than is privately optimal as a way of cutting GHG emissions.

Various schemes thus exist to promote investments in energy efficiency by industry. However, we should note that this actually brings about the possibility that GHG emissions will *rise*. This phenomenon is known as "backfire", and comes about because an increase in energy efficiency in production reduces the effective price of energy as an input. This causes (i) an output effect and (ii) a substitution effect, which both act to push total energy use back up again.

The output mix of the economy can also change towards more energy intensive goods (since production of such goods enjoys a relatively large increase in competitiveness), and an increase in export demands for energy intensive goods. Hanley et al (2006) investigate this phenomenon for the Scottish economy using a combined economic-environmental Computable General Equilibrium model, and find that a 5% improvement in energy efficiency across the board for the Scottish economy results in an increase in CO_2 emissions and a worsening of the GDP to energy use ratio.

4.2 Housing

Household energy use in the UK has risen over the last 30 years, mainly due to growth in energy demands for space heating, appliances and lighting. Encouraging households to reduce their energy consumption is one means of cutting Scotland's CO_2 emissions. Much emphasis has been given in policy discussions to the desirability of getting households to invest in energy efficiency (e.g. by insulating their homes, or buying more energy efficient consumer goods), and a range of policies have been implemented to encourage greater uptake of energy saving opportunities. For instance, the 2004 Energy White Paper sets a target of 5 MtC reduction in emissions from UK households. In one sense, we could argue that market forces will "look after" this target of government policy, since energy efficiency investments can save households money, and thus there is a selfish incentive to make the investment. Yet worry has been expressed that this incentive is not strong enough, either due to lack of information, high discount rates and the option value of delaying investments given technological advances are expected, or budget restrictions on the ability to pay for these investments. Moreover, since households do not face the full social costs of their own energy use – due to market failure – we could argue that the level of investment in energy efficiency which households choose to undertake is, from society's viewpoint, too low.

However, subsidising, mandating or otherwise encouraging households to improve their energy efficiency as part of climate policy only makes economic sense if the costs per tonne of carbon reduced are competitive with other ways for GHG emissions to be cut. Moreover, we need to understand what motivates households to invest in energy efficiency. Oxera (2006) report on a large survey of UK households which investigated the latter of these questions. Their conclusions were that future energy savings did not appear to be an important factor in motivating households, and that many households were very badly informed about the costs and benefits of different energy savings investments, tending to over-estimate costs. Measures by energy suppliers to persuade households to reduce energy consumption (mandated by the Energy Efficiency Commitment) seem particularly effective, and increase the impact of price subsidies for energy efficiency investments such as cavity wall insulation and loft insulation. Up-front costs were much more important determinants of willingness to invest in energy savings in the home than lifetime energy savings.

Oxera found that all the investments in household energy savings they considered had benefits (in terms of the value of energy savings) in excess of costs over the lifetimes of these investments, implying a *negative* cost of reducing GHG emissions for up to 3.5 - 4 MtC reductions per year which Oxera considered to be "realistically achievable". *In other words, the benefits of reducing energy consumption in peoples' homes, and thus of reducing carbon emissions, exceed the costs.* Since there is no reason to think that the Scottish case would be significantly different from the English data on which the Oxera study is largely based, this suggests that a policy to improve home energy efficiency should be part of any climate change policy in Scotland.

It also suggests that firms wishing to promote the sale of energy efficiency technologies need to put a lot of effort into closing the knowledge gap which the Oxera report highlights, and into reducing the transactions costs to consumers of taking up these energy saving options. Note however that the Oxera study did not allow for the kind of rebound or backfire effects noted above for industrial energy savings – consumers could increase energy consumption as the effective price of energy is lowered (the “turn up the thermostat” effect).

4.3 Transport

As noted in Section 1, transport is a growing source of GHG emissions in Scotland, currently accounting for 17% of emissions. For the UK, the growth in transport emissions during the 1990s was slower than would have occurred in the absence of the fuel duty escalator (Glaister, 2001), but in Scotland still grew by 6% from 1990 to 2003. However, the fuel protests of 2000 brought an end to this policy instrument. Growth in GHG emissions at the UK level from transport during the 10 years from 2000 to 2010 is predicted to be mainly due to the aviation sector, since increases in fuel efficiency will largely offset the growth in car mileage (DfT 2003). Whilst EU technological standards will drive down pollution levels per km for driving, the effect is more marked on pollutants other than GHGs, for example particulates and NOx. CO_2 emissions depend mainly on fuel consumption, which is related to distance travelled and engine size.

Setting fuel excise duty and vehicle taxes is a reserved matter, thus the Scottish Parliament could not at present use this policy option to reduce emissions in Scotland. Road pricing could though be introduced.
One worry about fuel taxes is their distributional impacts, in that they are generally thought to impact on poorer households proportionately more than richer households, since the former spend a higher fraction of their income on energy than the latter (Blow and Crawford, 1997). However, we could expect big variations in the impacts on poor households of higher fuel prices, since not all households have a car (non-car owning households are concentrated in the lowest income group), whilst rural households might loose out more than urban ones, since their average trip distance is longer, and poor rural households are more likely to be car users than poor urban households.

Dresner and Ekins (2004) look at the effects on different income groups of a range of transport initiatives, including:

- Increasing fuel duties (using a tax equivalent to £10 per tonne CO_2) and using the money to subsidise public transport
- Increasing fuel duties and using the money to increase means-tested welfare payments
- Congestion charging

They find that the lowest re-distributional effect (in other words, the option that penalises poor households to the lowest degree) is associated with increasing fuel duties and using the money to increase welfare payments. Increasing fuel duties and using the money (£633 million) to increase means-tested welfare payments has the effect of significantly reducing the number of low-income households who loose out.

Congestion charging which was high enough to tackle predicted traffic growth would raise significant revenue, but would benefit rural drivers at the expense of urban drivers if it was revenue neutral. Increasing fuel duties and subsidising public transport, in their simple analysis, produces as many losers as winners in the bottom two income deciles

A government wishing to reduce GHG emissions from transport by taxing car use and ownership should thus consider effects on low income households, although there are means to reduce these distributional effects. But economists would argue that, ideally, distributional and efficiency targets should be met using two sets of policies.

Finally, we could consider encouraging increased use of public transport rather than car journeys as a means of cutting GHG emissions. Studies have shown for Dublin that important factors underlying the decision to switch from car use to bus use for commuting include savings in journey time (through use of priority bus lanes), the chance of getting a seat, ticket prices and real-time information displays. Improving any of these attributes would increase the number of car drivers switching to bus use for travel to work (McDonnell et al, 2007).

However, we have not been able to discover any estimates for Scotland of the costs of reducing GHG emissions through investments in public transport, either in terms of avoided emissions form private cars, or of reduced emissions from trains and buses due to technological improvements.

4.4 Renewable Energy

As we saw above, energy supply is the largest single source of GHG emissions in Scotland, accounting for 37% of emissions. Policy towards the energy sector is thus very important in terms of overall climate policy. Electricity is a major element of energy consumption, and different generation sources have highly variable impacts on GHG emissions.

Table 3 below shows GHG emissions per kWh based on a life cycle analysis – that is, taking into account all resources used by a particular technology, including construction, fuel processing, operation and disposal:

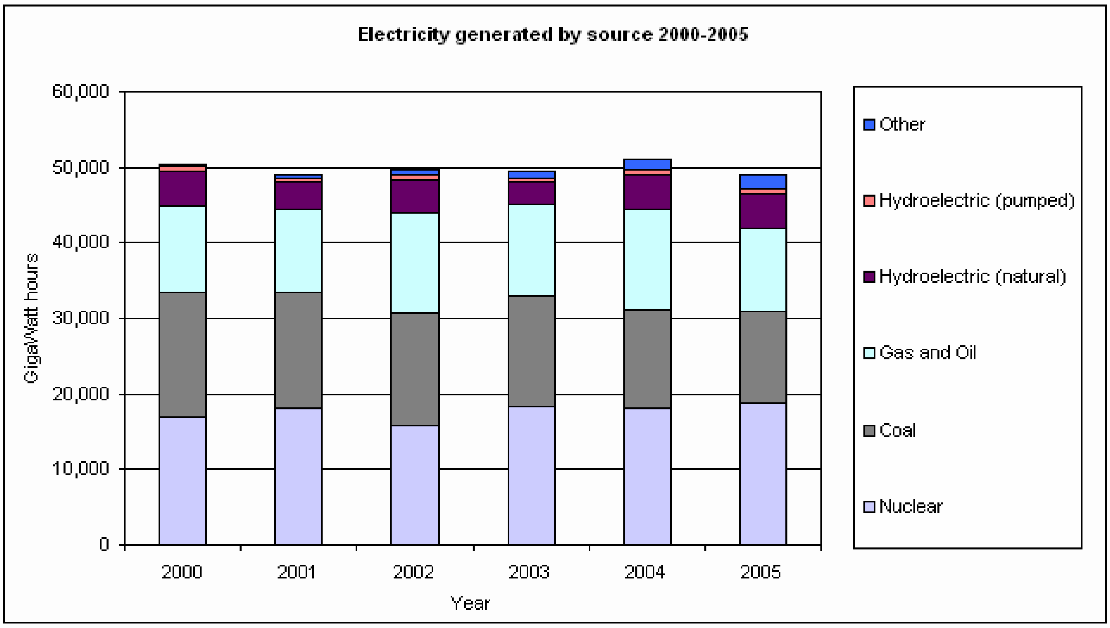
Table 3: Greenhouse Gas Emissions by Power Source

Generation Option	*Greenhouse gas emissions in CO_2 equivalents per kWh*
Hydro	2-48
Nuclear	2-59
Wind	7-124
Solar photovoltaic	13-731
Biomass (forestry waste combustion)	15-101
Natural gas combined cycle	389-511
Coal	790 – 1182

Source: International Energy Agency, 2000.

Overall emissions from electricity generation in a country thus depend on the generation mix: more coal in the mix pushes emissions up, more nuclear in the mix pulls emissions down. In 2002, emissions from the UK "average" generation mix were estimated to be 0.432 kg CO_2/kWh. For Scotland the estimate was 0.406 kg CO_2/kWh, the slightly lower CO_2 emissions estimated reflecting the greater proportion of nuclear and renewable power generation in Scotland (Scottish Energy Study: Volume 1). The Scottish value is decreasing (i.e. improving) as renewables increase, but will worsen significantly as nuclear power output declines (Hunterston B shuts down in a few years).

Figure 6: Electricity Generation by Source for Scotland, 2000-2005



Source: various

Promoting the expansion of renewable energy is a major element of the Scottish Executive's strategy on climate change.

The same remark also holds true for the UK government. As part of the Renewables Obligation (Scotland) Order the Scottish Executive set a target that 18% of electricity generated in Scotland by 2010 should come from renewable sources. Following consultation, the Scottish Executive announced in March 2003 its longer term aspiration that 40% of electricity generated in Scotland by 2020 should come from renewable sources. More recently this target has been revised to be the percentage of electricity consumed rather than the percentage of electricity generated in Scotland. The UK also has a target of 10% for electricity to be generated from renewables in 2010 and 20% by 2020.

In 2005, the amount of electricity generated in Scotland by renewable sources equated to 18.2% of the electricity consumed in Scotland, compared with 14.3% in 2000. Total power output from renewable sources (excluding hydro) grew from 306 Gwh in 2000 to 1,308 Gwh in 2004 (Scottish Executive, 2006).

Growth in especially on-shore wind power has been substantial in recent years, and this growth has been largely brought about by the complex and extensive intervention of the government in the electricity market. This, most importantly, includes the Renewables Obligation system and the Renewable Obligation Credits (ROCs) that flow from it, along with the Climate Change Levy and the EU Emissions Trading Scheme.

The Renewables Obligation Scheme was introduced in 2002. It sets targets for the minimum percentage of electricity supplied to domestic and business users which must come from renewable sources.
Supply firms buy this “required” green electricity from renewable energy producers, or can offset some of their obligation by (i) buying ROCs, which are earned by the supply companies by proposing new schemes, or by (ii) paying an opt-out fee known as the buy-out price. The additional costs of supplying electricity from renewables as compared with the cheapest source, and of providing back-up for when renewable supplies fail, is passed on entirely to electricity consumers, who thus pay for renewable energy expansion through higher bills. ROCs are tradeable, and have a market value of around £50 per MWh of installed capacity. As of 2009 a banding system for ROCs will be introduced, which will result in ROCs awarded for certain technologies, including off-shore wind and marine energy, having higher value than for on-shore wind. Note that this will involve the government in forecasting which technologies are likely to be preferred in the future – not something that governments are very good at.

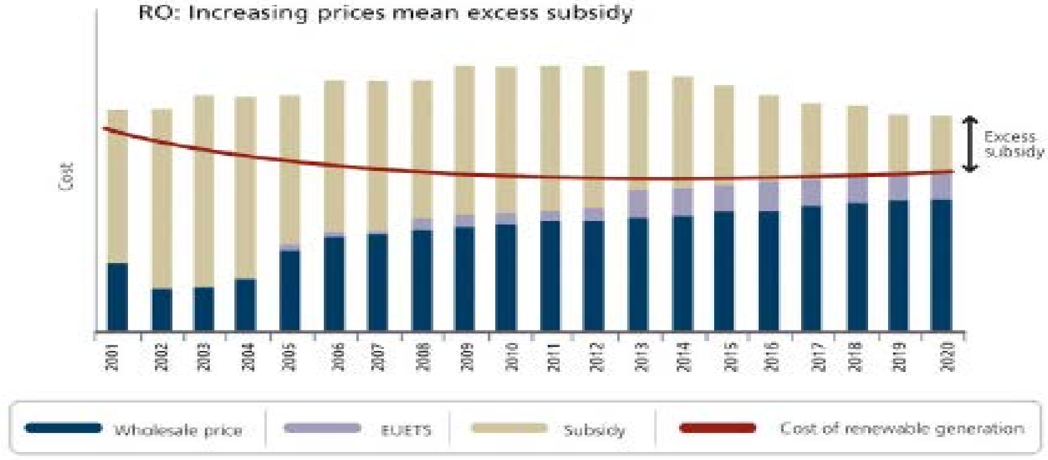
Electricity consumers are thus effectively subsidising private sector investment in new renewables as the Obligation system pushes up consumer prices and rewards investors in renewables with ROCs which can then be traded. In addition, renewable producers benefit from not having to buy carbon credits.

Recently, the UK system for supporting renewable energy has been criticised by Ofgem (2007), who stated that the system. “is a very expensive way of reducing carbon emissions compared to alternatives”. Ofgem estimated the cost of the RO system at over £1.7 billion to date to business and domestic customers, with an expected cost of £32 billion over the lifetime of the scheme.

They note that the scheme fails to link the value of ROCs with either the price of electricity or the price of EU carbon credits, and is leading to excessive returns to electricity producers at the expense of consumers. Linking the value of renewable support to electricity prices makes sense, since it is the total of these two values (plus the value of carbon credits) which determines the return to investment in new renewable capacity: and wholesale electricity prices have been rising recently. In a cost-effectiveness analysis, they compare the costs per tonne of *carbon* (not CO_2) reduced via the RO scheme of £184-481 (a figure of £400/tonne carbon is obtained if the average generation mix is used for the displaced fuel). These figures may be compared with the price of carbon permits (£12-£70 per tonne of C), the Climate Change Levy (£18-£40) and the Energy Efficiency Commitment (<£60/tonne). On these figures, as with the analysis for Scotland we report below, the Renewables Obligation Scheme seems to over-compensate investors at the expense of electricity consumers (see Figure 7 below), and fails a cost-effectiveness test for reducing GHGs.

Ofgem also considers that “there is little evidence that the scheme is encouraging technological development” – and thus that there is little evidence of cost-savings rising over time. Ofgem indeed calculate that at current electricity prices *no* subsidy is necessary for renewable producers to make normal profits given currently deployed technologies.

Figure 7: How the Renewables Obligation Scheme over-compensates electricity suppliers



Source: Ofgem, 2007

An obvious question is whether subsidising new renewable energy investments *in Scotland* is an economically-efficient means of reducing CO_2 emissions, through the displacement of fossil-fuel derived electricity with (for the most part) new wind energy. To evaluate this for Scotland, we calculate the cost of reducing one additional tonne of CO_2 from investing in (i) new onshore wind and (ii) new offshore wind, where the displaced power source is (a) coal or (b) gas.

Calculations are shown below for a number of cases: first, where the financial impacts of market intervention, notably the value of Renewable Obligation Credits, the Climate Change Levy and EU ETS carbon permits are included in the calculations, and perhaps more importantly, when they are excluded (Table 4).

The main facts that emerge from this analysis are that with no market intervention and assuming current prices, each extra tonne of CO_2 emissions we reduce from investing in onshore wind or offshore wind cost about £24 and £49 respectively if coal generation is the displaced source. This looks very expensive relative to the price of carbon permits on the EU ETS (£14/tonne at the end of September), suggesting that we are over-investing in renewable energy as a means of cutting carbon emissions from society’s point of view.
For displacement of gas as a generation source, costs per tonne of CO_2 reduced are £11 - £21/tonne. From society’s point of view, new on-shore wind power as a emission reduction strategy for gas displacement can make economic sense – although we make no allowance for the non-GHG external costs of either wind energy (e.g. landscape impacts) or fossil fuel energy (e.g. particulate emissions) in saying this.

Table 4: Costs of reducing one additional tonne of CO_2 by displacing fossil fuel generation with new renewables.

ROC, LEC and ETS included	*Onshore Wind*		*Offshore Wind*	
	Coal	Gas	Coal	Gas
Cost of switching 1 MWh	-36	-24	-28	-16
Cost of reducing 1 tonne of CO_2	-32	-8	-25	-5
Only ETS included	*Onshore Wind*		*Offshore Wind*	
	Coal	Gas	Coal	Gas
Cost of switching 1 MWh	18	29	46	57
Cost of reducing 1 tonne of CO_2	16	10	41	20
Only ROC and LEC included	*Onshore Wind*		*Offshore Wind*	
	Coal	Gas	Coal	Gas
Cost of switching 1 MWh	-27	-21	-19	-13
Cost of reducing 1 tonne of CO_2	-24	-7	-17	-4
Excluding all Gvmt intervention	*Onshore Wind*		*Offshore Wind*	
	Coal	Gas	Coal	Gas
Cost of switching 1 MWh	27	32	55	61
Cost of reducing 1 tonne of CO_2	24	11	49	21

Notes: ROC = renewable obligation credits; LEC = climate change levy exemption certificates; ETS = emissions trading scheme carbon permits. Calculations include capital costs, and assumes load factors of 35% for wind and 80% for coal/gas. CO_2 emissions per MWh are 0.9t for coal and 0.35t for gas. Assumes ROC price of £50 and banding factors of 1 for on-shore and 1.5 for off-shore.
Assumes £10/tonne for EU ETS and carbon-neutral standby generation for wind. Fuel prices are £15/MWh for gas and £16/MWh for coal. Main sources:
http://www.berr.gov.uk/files/file39038.pdf and
http://www.nowap.co.uk/docs/generation_costs_report.pdf

However, looking at the “with intervention” figures, we can see the private economic incentives behind investments in wind energy. Costs of switching from either coal or gas to either on-shore or off-shore wind are *negative.* We also see how the value of ROCs – a market created by the government to incentivise new investments in renewables - dominates these calculations. Note that these costs per tonne of CO2 displaced are in fact *under* estimates, since they exclude the reduction in consumers’ surplus due to higher electricity prices to consumers.

4.5 Agriculture

Agriculture may be a minor contributor to Scottish GDP, but as Section 2 showed, it is a major source and sink of GHGs in Scotland. Agricultural land management releases significant quantities of GHGs to the atmosphere worldwide, notably N_2O, CH_4 and CO_2, whilst agricultural soils also act as one of the world's main carbon stores (IPCC, 2007). In 2003 in the EU, emissions from agriculture account for about 10% of total emissions, whilst direct emissions from agriculture were 12% of total emissions in Scotland (excluding removals).

Three main types of strategy may be adopted to reduce net emission of GHGs via farm-related activities (Smith et al, 2007a):

- *reduce emissions*, for example by improving nutrient management
- *enhance removals*, for example by restoring wetlands or by reducing heather moorland burning
- *displacing emissions*, for example by growing bio-fuels which replace fossil-fuel derived fuels for heating or transport

IPCC (2007) present evidence on the effectiveness and potential (at a global scale) of particular methods within each of these 3 broad approaches. For instance, improved agronomic practices on cropland, reducing N losses, moving to low-tillage systems or set-aside of land can all reduce net emissions. Changing feeding practices and waste storage systems can reduce emissions from livestock systems. Promoting organic farming, if this results in an increase in soil organic matter, will also enhance removals.

The global, technical (i.e. ignoring economic considerations) potential of mitigation through agricultural change is estimated at between 4,500-6,000 $MtCO_2$-eq per year by 2030 (Smith et al, 2007a, IPCC 2007). Of this, 89% is from soil carbon sequestration, 9% from the mitigation of methane emissions and 2% from reductions in N2O emissions.

Some authors (e.g. Smith et al, 2007a; Rose et al, 2007) have also measured how much of this technical potential is economically viable, using a range of assumed world shadow prices for carbon, which are increasing in the severity of the GHG emission reduction target. These estimates are characterised by a wide range of uncertainty. For example, IPCC (2007) show a global mitigation in 2030 of 267-1518 $MtCO_2$-eq/year at a carbon-equivalent price of up to US$20/tonne, and 643-1866 $MtCO_2$-eq/yr. at a carbon price of $20-$50/tonne. Rose et al (2007), in a review of a large number of assessment models, conclude that both agriculture and forestry can be a cost-effective source of mitigation, and thus a significant contributor to a cost-effective programme.

They note a conclusion by Jakeman and Fisher (2006) that including agriculture and forestry in the options list globally for cutting net GHG emissions results in a predicted lower global cost for reducing emissions to “stabilization levels” from 7% to 2.3% of global GDP by 2050.

Because there is such a huge range of options through which GHG net emissions from agriculture can be reduced, it is hard to come up with point estimates of MACs for this source. These MACs will depend on the mitigation method adopted, and on the profitability of the farming system in which it is applied. Estimates do exist in the literature, and are integral in the studies assessed by Rose et al. A good example of the spatial variability in abatement costs is provided by de Cara, Houze and Jayet (2005). These authors use farm-level linear programming models for the EU-15 to estimate the optimal mix of abatement strategies for methane and nitrous oxide for a range of carbon prices[4]. Eleven emission "sources" and therefore, emission reduction options, are included in the model – for example, N_2O emissions from use of N fertiliser, linked to crop area, and methane from enteric fermentation, linked to animal numbers and feeding regime. They find that the optimal mix of emission reduction strategies varies considerably across countries and concluded that "..abatement cost heterogeneity (across regions) is a fundamental feature in the design of an (efficient) abatement policy". A tax rate of 55.8Euro per tonne of CO_2-eq. gives a 8% reduction in aggregate emissions, but the efficient degree of effort varies widely across the EU-15 according to the type and distribution of farms; for example, from 2% to 23%. They also show that economic incentives (in their case, an estimated emissions tax) allow for large cost savings in meeting abatement targets relative to command-and-control (uniform emission standards). For instance, the same 8% target reduction can be achieved using an estimated emissions tax at a total cost which is 2.2 times cheaper than a system of uniform estimated emission standards. However, this calculation ignores policy implementation costs.

The main options for GHG mitigation in agriculture *in Scotland* arise from improved cropland management (sequestering carbon in mineral soils through improved tillage, biosolid management, improved agronomy and reducing N_2O emissions through improved fertilizer practice), improved grazing land management (through improved fertilizer and biosolid management) and restoration of cultivated organic soils. Croplands and grazing lands on mineral soils in Scotland (as of 2003; areas from agricultural census data minus that occurring on organic soils) cover ~564 and 1035 kha, respectively, and cultivated organic soils (Countryside Survey, 1998) occupy about 79 kha. Using the per-area mitigation potentials for the cool-moist climate zone for different agricultural practices presented by Smith et al. (2007b), the technical GHG mitigation potential for Scottish agriculture (in 2030) is estimated to be 4.0 (2.2-5.4) Mt CO_2-eq. yr^{-1}, comprising 0.5 (0.3-0.7) Mt CO_2-eq. yr^{-1} from cropland management, 0.8 (0.5-1.2) Mt CO_2-eq. yr^{-1} from grazing land management, and 2.7 (1.5-3.5) Mt CO_2-eq. yr^{-1} from restoration of cultivated organic soils.

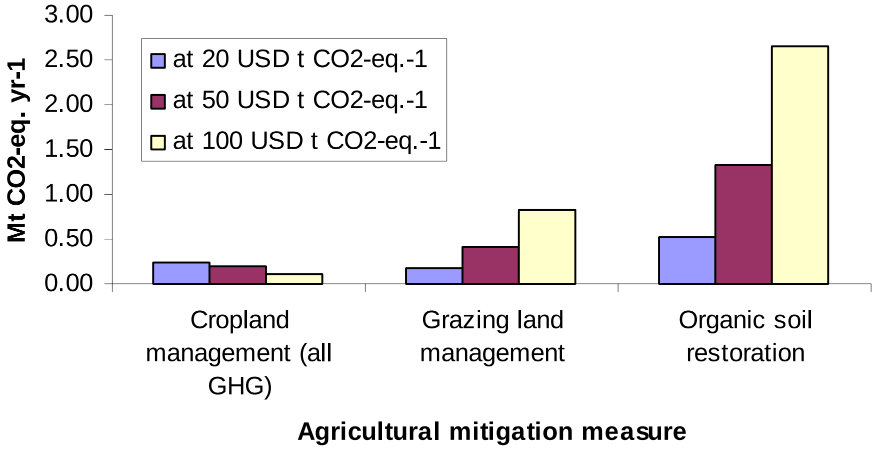
Assuming the same marginal abatement cost (MAC) relationships used by Smith et al. (2007b), derived using either European or global MACs defined in US-EPA (2006), the economic mitigation potential for all agriculture in Scotland is estimated to be 0.9 (0.5-1.3) Mt CO_2-eq. yr^{-1} at 20 USD t CO_2-eq.$^{-1}$, 1.9 (1.1-2.7) Mt CO_2-eq. yr^{-1} at 50 USD t CO_2-eq.$^{-1}$, and 3.6 (2.0-4.9) Mt CO_2-eq. yr^{-1} at 100 USD t CO_2-eq.$^{-1}$.

---

[4] The authors exclude carbon sequestration options from their analysis.

At low carbon prices, the combined mitigation potential of the relatively inexpensive option cropland and grazing land management is similar to that of organic soil restoration, but as carbon price increases, the mitigation potential of the more expensive organic soil restoration becomes much greater (nearly 3 times the combined potential of cropland and grazing and management at 100 USD t CO_2-eq.$^{-1}$; see Figure 8).

Figure 8: Mitigation potential of cropland management, grazing land management and restoration of cultivated organic soils in Scotland by 2030 at different carbon prices.



Source: own calculations (P.Smith)

In the above figure, the cumulative mitigation from grazing land management and organic soil restoration increases as the shadow price of carbon increases. This is because a rising shadow price of carbon makes increasingly expensive agricultural mitigation measures become cost-effective.

For cropland management, cumulative mitigation falls with rising carbon prices, because relatively cheap but ineffective (in GHG reduction terms) strategies are replaced in the cost-effective mix.

4.6 Forestry

The forest sector is, like agriculture, a small player in the Scottish economy, but a major player in net carbon emissions, and likely to become more so over time. Currently, Scotland is a net sink for carbon, represented in the official inventory figures as “Land Use Change and Forestry”, and the size of this net sink (removals minus emissions) has increased by 61% from 0.8 MtC in 1990 to 1.3 MtC in 2003. This is due to a 20% increase in removals, primarily through forest growth (Scottish Executive, 2006).

Planting new forests to lock up carbon dioxide has proved to be an idea of increasing interest to academics and to the forestry sector.

Forests absorb carbon as they grow, and can reduce the requirement to reduce emissions from other sources over a variable time period, depending on the nature of management, Clean Development Mechanism deals under Kyoto could in the future include forest planting. Private companies are already buying and selling carbon sequestration in UK forests.

Within Scotland, the Forestry Commission has publicised the basic analytics of carbon storage (FC, 2003), whilst private brokers are emerging who will sell carbon storage in forests to a wide range of clients, including supermarkets and transport companies. Prices offered (which reflect both supply prices and customer demand) are currently around £750-£1500 /ha for new "planting for carbon", and planters are claiming that this payment is needed to turn a no-planting decision into a planting decision. Interestingly, this compares with the location premiums of £1500 per ha offered by the Commission in recent years to encourage new planting in Ayrshire and Central Scotland, which was over-subscribed (indicating that for many landowners, £1500/ha exceeded the private loss from new planting).

Quantifying the costs of carbon storage in forests depends on a number of factors, including the growth rate of trees, the costs of planting, and the opportunity costs of land use. For example, in an analysis for the Ukraine, Nijnik (2005) shows that the PV of costs per tonne of C uptake ranges from £3 to £115, depending on the agricultural productivity of the land and on the discount rate used.

For Scotland, Hart calculates figures for the total costs of forest planting per tonne of CO_2 sequestered, using a range of assumptions about (i) how long the forest takes to reach equilibrium in terms of carbon storage (ii) the yield class and species of trees and (iii) the price of land. Planting grants (typically around £800-£2500 per ha.) are excluded since we are interested in the social cost of carbon sequestration. Table 5 shows some example calculations for tonnes/C per ha sequestered, whilst Table 6 shows results for costs per tonne of CO_2 organised by land price and sequestration amount.

As may be seen, this *average cost* per hectare varies considerably, from around £4 to £15 per tonne of CO_2. Higher land prices increase the cost per tonne CO_2 sequestered, higher sequestration rates reduce it. Note though that the landowner has a valuable asset as a result of the planting, the benefits of which are not included. Also note that we could expect this supply price for C sequestration by forests to vary across time and space. Future timber prices are expected to rise, which would reduce the required carbon subsidy. However, rising prices might also encourage more felling of existing woodlands, since the opportunity cost of leaving woodland standing is now greater. A large increase in forest planting globally for C sequestration would itself have an effect on the world price of timber. Changes in market interest rates would also have an effect, since this would change the test rate of discount in internal rate of return calculations.

Table 5: Calculations for C sequestration in selected woodland planting schemes

Species and management regime	Yield Class	Tonnes carbon/ha
Oak Scotland lowland	4	160
Oak Scotland upland	4	160
Oak Scotland upland	4	160
Birch Scotland upland	6	105
Birch Scotland upland	6	110
Birch Scotland lowland	6	130
Sitka Spruce thinning lowland	16	45
Sitka Spruce thinning upland	18	50
Scots Pine no thinning upland	12	115
Scots Pine no thinning upland 2 rotations	12	220
Sitka Spruce fell and restock continuous	12	70-100

Notes: figures exclude C changes in soils or in litter. Hardwoods given as equilibrium by 200 years (oak) and 100 years (birch). Softwoods given as average over 1st rotation unless noted.

Source: Hart (2007)

Table 6: Example calculations for costs of C sequestration by new woodland planting in Scotland.

Tonnes CO_2	*Examples*	*Planting cost/ha*	*Land cost £*	*Total cost£/TCO_2*
600	Oak, uplands	2500	1000	5.83
800	Scots pine, upland, 2 rotations	2500	1000	4.38
600	Scots pine, upland, 2 rotations	2500	1500	6.67
300	Sitka spruce with thinning, lowland	2500	2000	15.00
400	Birch, upland,	2500	2000	11.25
600	Birch, upland,	2500	2000	7.50
600	Birch, upland,	2500	3000	9.17
600	Oak, lowland	2500	5000	12.50
800	Oak, lowland	2500	5000	9.38

Notes: tonnes CO2 taken from previous table. Land costs and planting costs range over current market conditions for private sector.

Source: Hart (2007).

However, the emergence of an “official” market in C credits for forestry would depend on the EU allowing new sequestration to offset emission reduction requirements, so that carbon credits from forests could trade alongside CDM and EU ETS credits. Moreover, the growth of the current voluntary market in Scotland will depend on how the market and other institutions address four problem areas.

These are:

- Verification of new planting and that planted forests remain un-felled for the contract period. Monitoring costs could be high for contracts of up to 100 years in duration, and for small forest blocks.
- The assessment of additionality. If new forests would have been planted anyway without payment of the carbon credit, then is any new absorption created? How can additionality be measured, and how can the additional costs of creating carbon forests be measured? One idea is to compare the Internal Rate of Return (IRR) for forest planting with a test rate of discount (or required rate), and then calculate what additional payment is needed for the IRR to exceed this test rate. Who would do this? This additional payment would vary by land type (since land costs are variable). However, landowners may have multiple motives for planting forests, which means that even a forest with an IRR < test rate might still get planted. An additional complication relates to planting for carbon using planting grants which are rationed: additional forests planted for carbon mean less grants available for others, so marginal plantations get displaced.
- How to standardise the calculation method behind credits. For instance, we need agreed-on methods for assessing carbon storage over time, and on converting from tonne-years to permanent tonnes, to use the IPCC's nomenclature (IPCC, 2000). Should forest carbon credits also have an expiry rate of the length of the plantation?
- Competitive bidding for carbon planting payments would reduce the costs of achieving GHG stock reductions through this route, since as we have seen, the costs of sequestration are likely to be highly variable across landowners.

5. Abatement versus adaptation: what makes more sense for a small country?

5.1 Adaptation as a policy option

Adaptation means taking actions now to reduce or avoid damages in the future. As such, it should be part of overall climate policy. Given that Scotland is a very small player in terms of global emissions, it might be argued that resources would be better devoted to adaptation (reducing future damages) rather than mitigation (reducing emissions), since costly Scottish emission reductions will only have a tiny role to play in reducing the stock of global GHGs, whilst the benefits of adaptation accrue entirely to Scotland PLC. Moreover, adaptation can make sense even if the big players in global emissions (the US, India, China) refuse to take meaningful actions to cut emissions.

In general, *adaptation policy* in the case of climate change could involve:

➔ Actions that reduce the impacts of climate change, such as:

- Investing in flood defences, including coastal and estuarine defences; managed retreat for flood-prone land
- Land use change to fit changed environmental conditions, for example changing where we build new housing; changing agricultural systems.
- Encouraging changes in the economy which makes it less "climate vulnerable"

➔ Actions that pool or transfer the risk of change (Insurance)

➔ Actions that enhance the effectiveness of adaptation

- Markets in the effects of climate change (e.g. catastrophe bonds)
- Institutions to support adaptation (e.g. to raise and distribute international development assistance).

Note that market forces and individual actions by firms and households will bring about some of these actions without the government doing anything; although society can more efficiently spread risks from future climate change than can any individual. The economic principle to be used in all cases is that adaptation actions should be undertaken so long as the reduction in expected costs (in terms of the present value of avoided damages) exceeds the costs of the action taken. For example, this could mean investing in better flood management systems so long as the costs are less than the value of expected damages from flooding over time, discounted to the present. We therefore need to know what impacts on the economy climate change is expected to have, to think about these actions.

5.2 Predicted Effects of climate change for Scotland

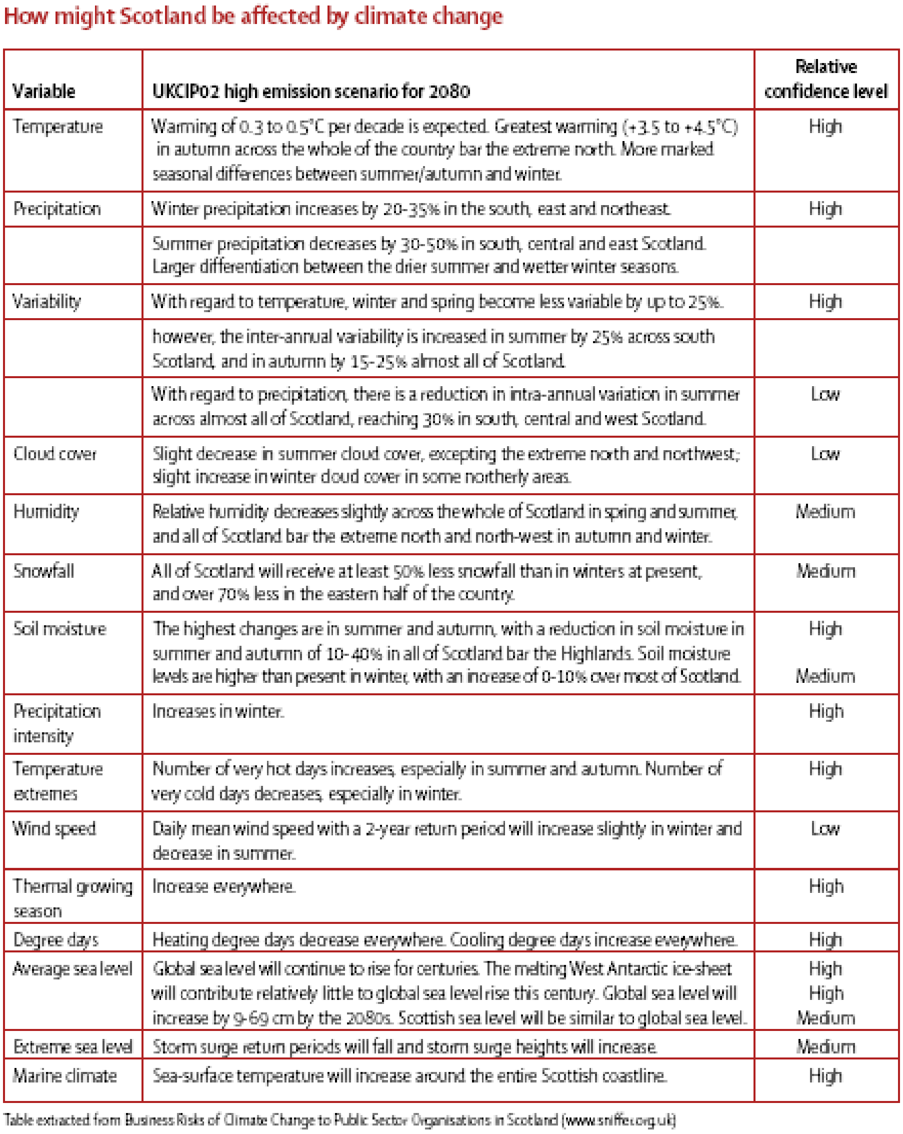
According to Climate Change Scenarios for the UK, published by Defra in April 2002, annual temperatures across the UK may rise by between 2 and 3.5ºC by the 2080s while warming will generally be greatest in parts of the southeast. Winters will become wetter and summers will become drier. Heavy winter precipitation will become more frequent, but the amount of snow may decline by 60 per cent or more in parts of Scotland and up to 90 per cent elsewhere by the 2080s. In general, "by the end of this century Scotland will have warmer, wetter winters, less snowfall and an increased risk of flooding"[5]. However, there is likely to be marked regional variation in the general trend, for example between the south east and north west of Scotland in terms of summer rainfall (Hulme et al, 2002). According to the findings of the"Climate Change: Scottish Implications Scoping Study"[6], Scotland may lose some bird species such as the ptarmigan and snow bunting while the marine fisheries of the North Sea and North Atlantic, and freshwater salmon and sea trout fisheries of Scotland's rivers, may be affected by changing ocean circulation. Figure 8 below, taken from Scottish Executive (2006) summarizes the main predicted effects for Scotland.

---

[5] http://www.scotland.gov.uk/Topics/Environment/Climate-Change/16327

[6] http://www.scotland.gov.uk/Resource/Doc/156611/0042072.pdf

Figure 8



How might Scotland be affected by climate change

Variable	UKCIP02 high emission scenario for 2080	Relative confidence level
Temperature	Warming of 0.3 to 0.5°C per decade is expected. Greatest warming (+3.5 to +4.5°C) in autumn across the whole of the country bar the extreme north. More marked seasonal differences between summer/autumn and winter.	High
Precipitation	Winter precipitation increases by 20-35% in the south, east and northeast.	High
	Summer precipitation decreases by 30-50% in south, central and east Scotland. Larger differentiation between the drier summer and wetter winter seasons.	
Variability	With regard to temperature, winter and spring become less variable by up to 25%.	High
	however, the inter-annual variability is increased in summer by 25% across south Scotland, and in autumn by 15-25% almost all of Scotland.	
	With regard to precipitation, there is a reduction in intra-annual variation in summer across almost all of Scotland, reaching 30% in south, central and west Scotland.	Low
Cloud cover	Slight decrease in summer cloud cover, excepting the extreme north and northwest; slight increase in winter cloud cover in some northerly areas.	Low
Humidity	Relative humidity decreases slightly across the whole of Scotland in spring and summer, and all of Scotland bar the extreme north and north-west in autumn and winter.	Medium
Snowfall	All of Scotland will receive at least 50% less snowfall than in winters at present, and over 70% less in the eastern half of the country.	Medium
Soil moisture	The highest changes are in summer and autumn, with a reduction in soil moisture in summer and autumn of 10-40% in all of Scotland bar the Highlands. Soil moisture levels are higher than present in winter, with an increase of 0-10% over most of Scotland.	High Medium
Precipitation intensity	Increases in winter.	High
Temperature extremes	Number of very hot days increases, especially in summer and autumn. Number of very cold days decreases, especially in winter.	High
Wind speed	Daily mean wind speed with a 2-year return period will increase slightly in winter and decrease in summer.	Low
Thermal growing season	Increase everywhere.	High
Degree days	Heating degree days decrease everywhere. Cooling degree days increase everywhere.	High
Average sea level	Global sea level will continue to rise for centuries. The melting West Antarctic ice-sheet will contribute relatively little to global sea level rise this century. Global sea level will increase by 9-69 cm by the 2080s. Scottish sea level will be similar to global sea level.	High High Medium
Extreme sea level	Storm surge return periods will fall and storm surge heights will increase.	Medium
Marine climate	Sea-surface temperature will increase around the entire Scottish coastline.	High

Table extracted from Business Risks of Climate Change to Public Sector Organisations in Scotland (www.sniffer.org.uk)

The transport sector is regarded as likely to be affected by increased risks of flooding, storms, and sea level rise. Hence, flooding of roads and railways by rivers, and an increased probability of landslides, may be some of the negative impacts in the transport sector. As positive effects we could expect reduced road delays and damage from snow and frost. Investments could clearly be made to reduce these expected costs. In the energy sector, the significance of renewable energy sources is likely to increase.

Benefits are expected to occur from an increase of the mean wind speed which will favour the potential of renewable sources, such as wind and wave power schemes as well as the faster growth of biomass plantations due to elevated CO_2 concentrations. Furthermore, energy consumption may well fall as a consequence of higher winter temperatures.

However, although this will reduce domestic and business heating bills, it could as well reduce turnover for power utilities. Finally, there is concern that increased sea-level may cause flood damage to coastal energy installations.

For the business sector, apart from reduced energy use for winter heating, tourism is expected to be favoured by summer warmth and spring dryness. On the other hand, increased inland and coastal flooding and increased energy requirements for cooling manufacturing processes, due to temperature rise, are considered as negative climate impacts of the sector.

For all sectors, climate effects include flooding in low-lying coastal areas and areas close to rivers, with increased costs and disruption of services by coastal flooding and flooding of rivers. Furthermore, an impact of increased winter run-off from land on water quality could occur. Changes in ocean currents and biodiversity could translate into reduced availability of food for fish and recruitment to breeding stocks, to the impact of increased flash flooding of rivers on fish habitat, to the competition from coarse fish favoured by higher temperatures and lower oxygen concentrations, the increased incidence of forest pests and wide spread of crop diseases, and increased tree damage and blow-down. However, agriculture might benefit due to higher CO_2 fertilisation and other effects (see Hanley et al, 2006b).

The importance of adaptation policy lies in the response by all sectors to the range of anticipated climate changes. In this framework two important adaptation responses relate to the planning system. As it is stated in Scottish Executive, 2006 (p.79): “the planning system has a key role to play in avoiding flood risk by ensuring a balance between a constraint on activities because of adverse climate risk and maintaining an acceptable level of development”.

To conclude, we can say that climate change will have a range of predicted effects on firms and households in Scotland, and that we can expect these agents to respond to these changes in risks by changing their behaviour. In general, a rational approach is to compare the avoided costs of impacts with the costs of changing behaviour, but this is difficult if predicting impacts is uncertain. Governments have a role to play since they can alter institutions to make the system more resilient, but we would not wish public spending on risk reductions to crowd out private spending. Understanding what constitutes an economically-sensible adaptation policy requires us to understand both the predicted effects of climate change and the response of economic actors to changes in risk. The business sector will respond to climate change risks, for example in terms of insurance provision, and this enhanced risk itself provides opportunities for entrepreneurship.

6. Implications for Business

Economic theory suggests that ‘*the social costs of reducing pollution will be minimised when marginal abatement costs are equalised across polluters*’. The implications of reducing green house gases for business will depend greatly on how easily this can be achieved if, indeed, it is possible at all.

It is more likely that governments will continue to take a predominantly regulatory approach to climate change, which will maintain differentials in marginal abatement costs across businesses. This will be an on-going source of economic inefficiency. How any climate policy impacts on individual firms though will depend on policy choice and individual circumstances. Some businesses will benefit in this new environment to the detriment of others.

Currently, there are a number of schemes used to promote investments in energy efficiency by industry. However, at the moment, not many sectors are impacted and, in the case of the Climate Change Levy, the UK government provides tax relief to lessen the impact of the 'green tax'. If stricter carbon controls were imposed on Scottish businesses, the likelihood is that companies would have to invest more seriously in new technology, reduce output or switch to potentially more expensive types of fuel in order to reduce their GHG emissions. The overall result of all three possibilities, in the short term, would be to raise companies' unit costs. Longer term savings may accrue from investment in new technology but these can take some time to feed through to the 'bottom line'. The existence of the permit market allows companies which have lower emissions to sell permits to those which have higher emissions. But, again, buying permits raises costs for the latter.

There will also be opportunities for those companies producing the newer, cleaner technologies to sell to the 'polluters' discussed above. A drive towards cleaner production processes should mean that capital equipment will be replaced more quickly, benefiting both the companies who manufacture this equipment and those at the forefront of the change – the early adaptors. For example, in the energy business, if tighter carbon controls or higher carbon prices come about, those which have invested in a higher mix of renewable or nuclear energy production will benefit to the detriment of companies still mostly dependent on fossil fuels. BP has been investing in solar cells in a small way for the past thirty years; it is now investing heavily. In a joint venture with Tata, it expects to produce 300MW of solar cells a year by 2010. It is also undertaking a joint venture with an American turbine manufacturer to become a wind power generator. Similarly, in the car industry, producers of fuel efficient and electric cars will perform better under the new order than those manufacturing large 'environmentally unfriendly' vehicles.

Climate change poses challenges to business in terms of adapting to new situations and new policy initiatives, but also offers opportunities. For example, the creation of a market in carbon trading has opened up many opportunities for broking firms and for innovative reductions in carbon emissions globally. Both climate change itself and, probably to a greater degree, the policy response to it, also create opportunities with respect to the development of new technology. The principal example of this is the enormous incentives provided to the electricity industry to invest in renewable energy through the Renewables Obligation scheme. But other important examples exist, such as the development of Carbon Capture and Storage (CCS) technologies, which could become profitable under the UK climate change programme.

A report for the UK government suggests that British firms are well placed to develop and exploit this technology, due to the proximity of suitable carbon storage areas under the North Sea, and the complementarities of technology with enhanced oil and gas recovery. (Indeed, BP are investing in a \$600 million CCS plant at Peterhead, which would generate hydrogen from natural gas for use in power generation, and CO_2 for pumping back to the Miller oilfield to enhance oil recovery and for storage).

7. Conclusions

This paper raised the question: *How should Scotland respond to the issue of global climate change?* We mainly considered this in terms of what might constitute an economically efficient approach to achieving the target reductions in GHGs that Scotland faces. Two important conclusions from a brief review of the economic theory of pollution control were that economic incentives such as taxes and tradeable permits have important advantages over regulatory means of achieving targets; and that a cost-minimising approach to cutting emissions would be aware of differences in the marginal costs of cutting emissions or assimilating carbon across sectors.

Governments could in principal solve their worries over cost-effectively hitting GHG reduction targets if economic instruments were used to the widest extent possible, rather than regulatory measures. For Scotland, this would imply extending the EU permit trading scheme to the widest set of emission sources for which it was feasible, and then setting a carbon tax (or carbon-equivalent) to deal with all remaining sources. As we noted in Section 2, Professor Nordhaus has gone even further than this, suggesting that a global carbon price be agreed and applied world-wide. However, this seems politically unlikely to happen. Moreover, there are current disagreements as to how big this global carbon price should be. This is not surprising since the parameters which influence this price (the degree of expected damages, the desirable target for CO2 concentrations, the discount rate, and public willingness to pay for reducing GHG emissions) are so uncertain.

We thus turned to a “fine tuning by sector” approach. Despite a lack of detailed research for Scotland, we were able to come up with the following “back of the envelope” figures for variations in abatement costs across sectors (Table 7):

Table 7: *Summary of costs of reducing GHG emissions from different sources in Scotland.*

Sector	Costs per tonne CO_2 eq.	Comments
Industry	**£14**	**Current EU ETS price.**
Housing	**negative**	**Based on UK wide data**
Transport	**Not known**	**No Scottish research available**
Renewables	**£11 - £49**	**Depends on whether on- or off-shore wind and whether replaces coal or gas**
Agriculture	**£10**	**Can deliver up to 1 Mt/yr., but based on US/EU data**
Forestry	**£4-£12**	**Assumes additionality**

Source: own calculations

From the above figures, it would seem as if encouraging households to invest in energy efficiency is a "no brainer" from the viewpoint of GHG mitigation. Industry and agriculture can also both make useful contributions, and both are significant sources of emissions. Forestry can also make useful contributions, but only if the additionality problem can be solved, along with the other issues raised in section 4. Renewable energy only looks a cost-effective way of reducing GHG emissions in the case of on-shore wind replacing gas generation; whilst we have already noted that how this renewable capacity is currently encouraged has been criticised as being very expensive by the regulator. Moreover, the phasing out of electricity production from Scotland's existing nuclear power stations will begin in around 5 years time; this will clearly have implications for the costs of generating electricity from renewables, since a big gap in baseload capacity will emerge.

Scotland is a very small country from the perspective of global warming, in that actions taken by Scotland alone to reduce current and future emissions will have a trivial impact on the global GHG stock from which climate forcing originates. This would suggest that a rational response is to invest more in adaptation than in mitigation, so long as the benefits of individual mitigation measures – the reduction in future expected damages – exceed the costs. This kind of calculation is fraught with difficulty, however, since it is hard to predict future climate change, its implications for economic and environmental systems, and what human responses to these will be. It is also possible that government intervention to reduce climate risks will crowd out private actions to reduce risks and expected costs – we need evidence that the public provision of risk reduction is more efficient, in this context, than private provision.

More importantly though, Scotland, through the UK and EU governments, and through its own decisions, has established targets for cuts in GHG emissions, irrespective of the small country issue noted above. Given that this is the case, this paper shows that economic analysis can make a valuable contribution to understanding what constitutes a "best response" to these targets.

References Cited

Arrow K J (2007) “Global climate change: a challenge to policy” *Economists Voice*, June, 1-5, available at www.bepress.com/ev.

Baumol W and Oates W (1975) *TheTheory of Environmental Policy.* New York: Prentice Hall.

Blow L. and Crawford I. (1997) The distributional effects of taxes on private motoring. London, Institute for Fiscal Studies.

Burtraw, D. (1999) “Cost savings, market performance and economic benefits of the US acid rain programme” in Sorrell S and Skea J (eds.) *Pollution for Sale: emissions trading and joint implementation*. Cheltenham: Edward Elgar.

Convery, F. and Redmond, L. (2007), “Market and Price Developments in the European Union Emissions Trading Scheme”, *Review of Environmental Economics and Policy*, **1**(1), 88-111.

De Cara S., Houze M and Jayet P-A (2005) “Methane and nitrous oxide emissions from agriculture in the EU: a spatial assessment of sources and abatement costs” *Environmental and Resource Economics*, 32: 551-583.

Department for Environment Food and Rural Affairs’ (DEFRA), (2006) Demonstrable Progress: The United Kingdom’s Report on Demonstrable Progress under the Kyoto Protocol. (Available at: http://unfccc.int/resource/docs/dpr/uk1.pdf).

Department for Transport (2003) Modelling and forecasting using the National Transport Model. London: DfT.

Dresner S and Ekins P (2004a) “The distributional impacts of economic instruments to limit greenshouse gas emissions from transport” Discussion Paper 19, Policy Studies Institute, London.

Dresner, S., Ekins, P., (2004b) Charging for domestic waste: Combining environmental and equity considerations. Policy Studies Institute

Dresner, S., Ekins, P., (2004) Economic Instruments for a Socially Neutral National Home Energy Efficiency Programme. Policy Studies Institute

Ekins P. and Speck S. (2007) ‘Environmental Tax Reform in Europe: Energy Tax Rates and Competitiveness’, in Chalifour, N. et al. (Eds.) *Critical Issues in Environmental Taxation*, Vol.V, Oxford University Press, Oxford

Ellerman A.D., Schmalensee R., Joskow P., Montero J-P and Bailey E. (1999) “Summary evaluation of the US SO_2 trading programme” in Sorrell S and Skea J (eds.) *Pollution for Sale: emissions trading and joint implementation*. Cheltenham: Edward Elgar.

European Commission (2004), “Commission Decision Establishing guidelines for the monitoring and reporting of Greenhouse Gas Emissions Pursuant to Directive 2003/87/EC of the European Parliament and of he Council”, Brussels.

European Union.(2003), “Directive 2003/87/EC of the European Parliament and of the council of 13 October 2003 establishing a scheme fro greenhouse gas emission allowance trading within the community and amending Council directive 96/61/EC”. Brussels.

Forestry Commission (2003) Forests, Carbon and Climate Change. Edinburgh: Forestry Commission.

Glaister S (2001) UK Transport Policy. Lecture to the British Association for the Advancement of Science, University of Glasgow.

Goulder, L., (1995) Environmental Taxation and the ‘Double Dividend’: A Reader’s Guide. *International Tax and Public Finance* 2:157-183.

Hanley N D and Moffatt I "Efficiency and distributional aspects of market mechanisms in the control of pollution : an empirical analysis" *Scottish Journal of Political Economy,* 40, 69-87, February 1993

Hanley N, McGregor P, Swales K and Turner K (2006) The impact of a stimulus to energy efficiency on the economy and the environment: A regional computable general equilibrium analysis. *Renewable Energy,* 31 (2), 161-171

Hanley N, Oglethorpe D and Tinch D (2006b) “Predicting the regional impacts of climate change on agriculture” University of Stirling Discussion Papers in Economics.

Hanley N, Shogren J and White B (2007) *Environmental Economics in Theory and Practice (2nd edition).* Palgrave.

Hart, Simon (2007) Carbon Cost Model. UPM Tilhill Forestry, Stirling.

Hoel M and Karp L (2001) “Taxes and quotas for a stock pollutant with multiplicative uncertainty” *Journal of Public Economics*, 82: 91-114.

Hulme, M; Jenkins, GJ; Lu X; Turnpeny, JR; Mitchell, TD; Jones, RG; Lowe, J; Murphy, JM; Hassell, D; Boorman, P; McDonald, R and Hill, S (2002) *Climate change scenarios for the United Kingdom: The UKCIP02 scientific report*. Tyndall Centre for Climate Change Research; School of Environmental Science; University of East Anglia; Norwich.

IPCC (2000) *Land use , Land use change and forestry.* Cambridge University Press.

IPCC (2007) *Fourth Assessment Report: Agriculture.* Cambridge University Press.

Jakeman G and Fisher B (2006) “Benefits of multi-gas mitigation: an application of the GTEM model” *Energy Journal,* special issue 3.

Kruger, J. and Pizer, W. (2004) "The EU Emissions Trading Directive: Opportunities and potential pitfalls". Discussion Paper 04-24, Resources for the Future, Washington DC.

McDonnell S., Ferrera S and Convery F. (2007) "Bus priority provision and willingness to pay differentials" Paper presented to the European Association of Environmental and Resource Economists conference, Greece. www.eaere2007.gr.

McKenzie I, Hanley N and Kornienko T (2007) "The optimal initial allocation of tradeable permits" *Environmental and Resource Economics*, forthcoming

Missfeldt F and Hauff J. (2004) "The role of economic instruments" in Owen A. and Hanley N. (eds.) *The Economics of Climate Change*. Routledge

Moffatt I (2004) "Global warming: scientific modelling" in Owen A. and Hanley N. (eds.) *The Economics of Climate Change*. Routledge.

National Center for Environmental Economics (2004) *International Experiences with Economic Incentives for protecting the environment* Washington DC: US Environmental Protection Agency.

Nijnik M. (2005) "Economics of climate change mitigation forest policy scenarios for the Ukraine" *Climate Policy* 4, 319-336.

Nordhaus W. (2007) "To tax or not to tax: alternative approaches to slowing global warming" *Review of Environmental Economics and Policy*, 1: 26-44.

Ofgem (2007) *Reform of the Renewables Obligation 2006: Ofgem's response*. Office of Gas and Electricity Markets, London, January.

Oxera (2006) *Policies for energy efficiency in the UK household sector*. Report to DEFRA, January.

Parry, Ian W. H., (1995) "Pollution Taxes and Revenue Recycling." *Journal of Environmental Economics and Management* 29: S64-77.

Parry Ian H. (2003) "Fiscal interactions and the case for carbon taxes over grandfathered carbon permits" Resources for the Future Discussion Paper 03-46.

Popp D. (2004) "ENTICE: endogenous technological change in the DICE model of global warming" *Journal of Environmental Economics and Management*, 48 (1), 742-768.

Rose**,** S., H. Ahammad, B. Eickhout, B. Fisher, A. Kurosawa, S. Rao, K. Riahi, and D. van Vuuren, (2007) *Land in Climate Stabilization Modeling*. Energy Modeling Forum Report, Stanford University.
http://www.stanford.edu/group/EMF/projects/group21/Landuse.pdf

Scottish Executive (2006), Changing our ways: Scotland's Climate Change Programme, Edinburgh.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H.H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, R.J., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Rose, S., Schneider, U. & Towprayoon, S. (2007a) Agriculture. Chapter 8 of *Climate change 2007: Mitigation*. Contribution of Working group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H.H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, R.J., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. & Smith, J.U. (2007b) Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society, B.* **363**. doi: 10.1098/rstb.2007.2184.

US-EPA, 2006: *Global Mitigation of Non-CO_2 Greenhouse Gases*. United States Environmental Protection Agency, EPA 430-R-06-005, Washington, D.C. < http://www.epa.gov/nonco2/econ-inv/downloads/GlobalMitigationFullReport.pdf > (accessed 26 March 2007).

Zapfel, P. (2005), "Greenhouse Gas Trading in the EU: Building the World's largest Cap-and-Trade System", In *Emissions Trading for Climate Policy: US and European Perspectives*, Hansjürgens, B. (Ed.), Cambridge: Cambridge University Press

Annex 1

Figure 1

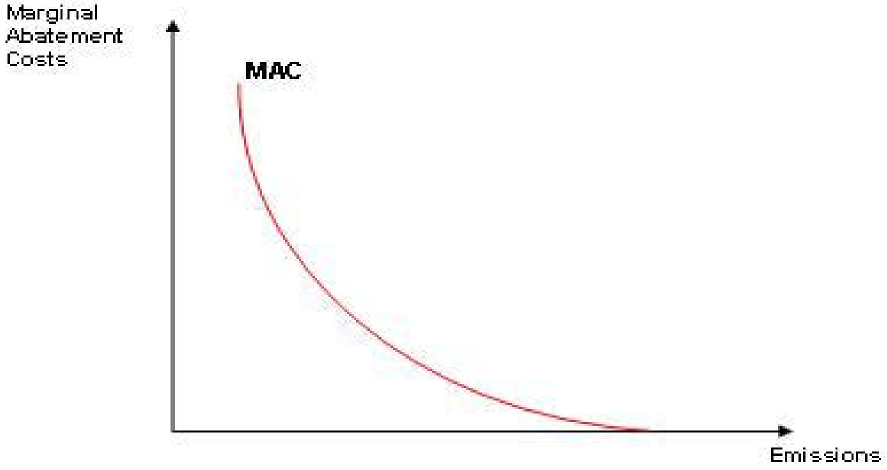


Figure 2

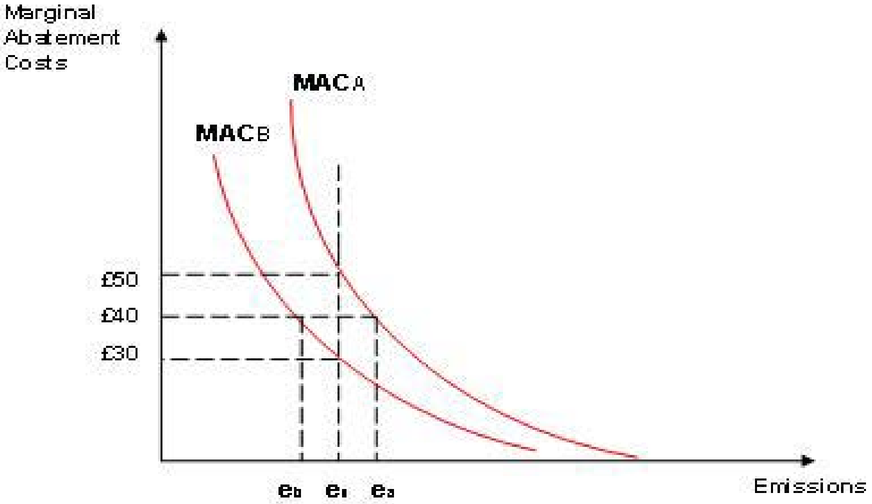


Figure 3

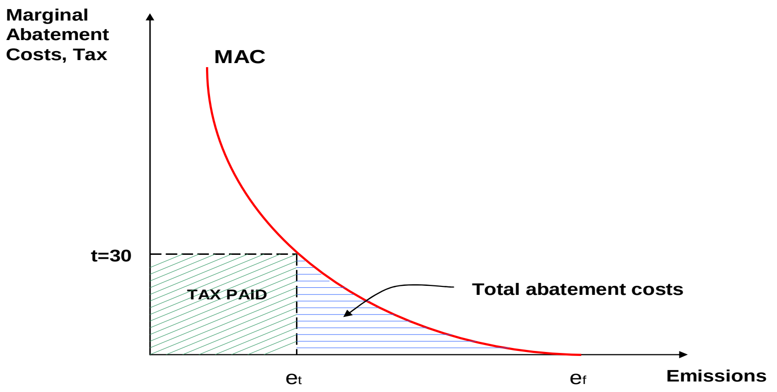
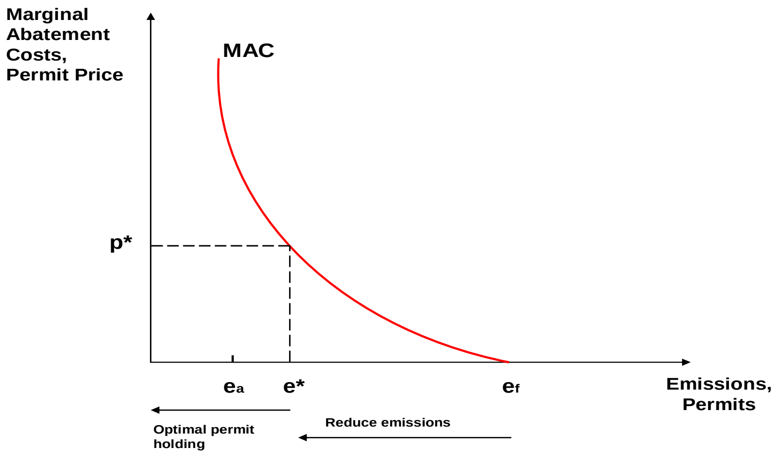


Figure 4



THE DAVID HUME INSTITUTE

The David Hume Institute

The David Hume Institute was registered in January 1985 as a company limited by guarantee: its registration number in Scotland is 91239. It is recognised as a Charity by the Inland Revenue.

The objects of the Institute are to promote discourse and research on economic and legal aspects of public policy. The Institute has no political affiliations.

The Hume Occasional Paper series presents papers by members of the Institute, by those who have lectured to it and by those who have contributed to "in-house" projects. A selected list of Occasional Papers follows:

66 *Regulation and Politics: The need for a new dialogue Or A letter to John Redwood* (The Hume Lecture 2004)
Sir Howard Davies

67 *Balancing Regulation and Competition in the Water Business in Scotland*
Sir Ian Byatt

68 *The European Union and the Idea of a Perfect Commonwealth*
(The Hume Lecture 2006) Sir Neil McCormick

69 *The Scottish public Sector: Does Size Matter?*
Richard Marsh and Fabian Zuleeg

70 *Rethinking Local Government Relations in Scotland: Back to the Future*
Jim Gallagher, Kenneth Gibb and Carl Mills

71 *A Wise Man Proportions His Beliefs to the Evidence: Scepticism and Competion Policy*
Peter Freeman

72 *Financial Fitness Programme for Young Scots: A report on the need to strengthen the provision of financial education in Scottish Schools*
Peter Jones