The case for carbon pricing

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Executive summary

- A uniform global carbon price (and prices on other greenhouse gases in proportion to their warming potential), delivered either by carbon taxes or carbon trading, would be an ideal tool to reduce greenhouse gas emissions sharply in a cost-effective way, based on the principle that the 'polluter pays'. In practice, this will be difficult to achieve but the principle remains a vital yardstick with which to assess actual policy measures.
- A uniform global carbon price would act as a pervasive encouragement for businesses to adjust their investment, their mix of inputs and their innovation away from greenhouse-gas-intensive technologies, and for consumers to reduce their spending on high-carbon products.
- It is difficult to be sure what the precise level of the carbon price should be and how exactly to introduce it country by country, including whether by carbon trading or carbon taxes, but the broad direction for policy is clear.
- The UK's Committee on Climate Change has suggested that a price of £30 per tonne of carbon-dioxide-equivalent in 2020, rising to £70 in 2030, would be consistent with achieving UK Government targets for emissions reductions. It is argued here that it might be preferable to move more rapidly towards a price of the order of £30 per tonne of carbon-dioxide-equivalent, while taking due account of structural adjustment costs and the macroeconomic environment. But the price could then rise more slowly than suggested by the Committee.
- The key point is that a carbon tax or trading scheme can and should be revised over time as policy-makers learn from experience. Given the extent of uncertainties and debate about the science, economics and ethics, policy-makers will have to be ready to engineer changes in the expected price trajectory over time as evidence is collected about the costs of emissions reductions, the risks of climate change and the pace of low-carbon innovation.
- It is also important to encourage policy-makers in the UK and other countries to move towards a uniform carbon price across sectors so that the burden of adjustment costs is spread efficiently across economies and thus minimised. Promoting cost-effectiveness is also likely to promote political acceptability.
- Policy-makers will also have to consider the distributional consequences of carbon pricing, which could be problematic if compensatory measures are not taken. The potential revenue from charges on carbon or from emission quota auctions allows the incidence of carbon pricing on the disadvantaged to be offset to some extent. But policy-makers are unlikely to have all the information necessary to do so entirely.
- The consequences for competitiveness have to be assessed, too. They seem unlikely to be substantial. However, the possibility of switching to levying a carbon price on the embedded carbon in all domestically consumed goods and services, whether produced domestically or abroad – for example, by means of border tax adjustments – should be considered as a potential policy option.
- Other policies are needed, too, particularly to promote innovation and appropriate infrastructure investment, but cannot be relied upon by themselves to bring about the necessary reductions in emissions. Carbon pricing is crucial.
- A major challenge for policy-makers is to communicate to businesses and the public why carbon pricing is a sensible option. To do this, policy-makers must explain very clearly the nature of the market failure that means the current prices of goods and services do not fully reflect the expected costs of climate change impacts which will be borne by future generations. A failure to explain the rationale for carbon pricing in terms of the 'polluter pays' principle could jeopardise public acceptance and support.

1. Introduction

Human-induced climate change poses enormous risks to our environment, economies and societies. Nations have come together under the auspices of the United Nations to debate what needs to be done to manage these risks.[1] They have agreed that it is prudent to attempt to limit the increase in the global mean temperature to 2°C or less and have recognised that that entails sharp reductions in annual global emissions of greenhouse gases over the next few decades.[2] But how is that to be achieved? This policy brief outlines the arguments for a broadly uniform carbon price as a key part of the policy framework in the UK and other countries. It is by no means the only policy tool needed but it is essential if a cost-efficient and fair solution to the challenge of human-induced climate change is to be found.

This policy brief outlines the arguments for a broadly uniform carbon price as a key part of the policy framework in the UK and other countries.

The case for carbon pricing rests on the economic analysis of 'externalities' – circumstances where the effect of production or consumption of goods and services imposes costs or benefits on others that are not reflected in the prices charged for those goods and services. This case is laid out in Section 2. Having established the case for carbon pricing, Section 3 tackles the challenge of deciding what the price should be. In Section 4, the practical policy question of how to introduce a carbon price is addressed. Carbon pricing affects the distribution of income and wealth as well as the incentives to emit greenhouse gases; some of the issues to which this gives rise are discussed in Section 5. Section 6 develops the argument that, while other policies are needed too, in particular to promote innovation and energy saving, it would be a big mistake to rely on them alone to halt human-induced climate change. Section 7 concludes.

1. The World Meteorological Organization and the UN Environment Programme jointly set up the Intergovernmental Panel on Climate Change (IPCC) in 1988, which was endorsed by the UN General Assembly that year. The UN Framework Convention on Climate Change (UNFCCC) was launched at the UN Earth Summit in Rio de Janeiro in 1992 and came into force in 1994. Its ultimate objective is 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. The Convention has been ratified by 195 countries, and there are regular meetings of the Conference of the Parties (COP) to the Convention; COP17 is scheduled to take place in Durban, South Africa, in late 2011.
2. The 16th session of Conference of the Parties to the UNFCCC (COP16) in Cancùn, Mexico, in December 2010, agreed that 'deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global gas emissions so as to hold the increase in global average temperature below 2°C above pre-industrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity' (http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2).

2. The analytical case for carbon pricing

1. Making the polluter pay

The increasing emissions of greenhouse gases in the course of activities such as electricity production, driving cars and cutting down forests has upset the balance between the entry of greenhouse gases to the atmosphere and their removal by their absorption in the land and oceans and chemical transformation. The mounting concentrations of greenhouse gases in the atmosphere are bringing about global warming and climate change, thereby leading to a wide range of potential effects on the environment, economies and societies. These effects will differ by location and timing but it is very likely that most will be adverse, the more so the larger the global temperature increase. The risks of catastrophic outcomes rise with the temperature change.

Those who produce greenhouse gas emissions are therefore imposing potentially huge costs on other people over time. However, emitters of greenhouse gas pollution do not have to face the consequences of their individual actions, through markets or other ways, unless policy-makers intervene. If they can be made to do so, they will be discouraged from emitting as much and the products they make will become relatively more expensive, discouraging demand for them. The imposition of costs will also spur innovation to find less costly, less greenhouse-gas-intensive ways of providing goods and services. This is the basic case for putting a price on greenhouse gas emissions by deliberate policy measures.

A tonne of carbon dioxide emitted today will have practically the same impact on climate change whether it originates in London, New York or Mumbai.

The greenhouse gases produced by economic activities mix rapidly with other gases in the atmosphere and most remain in the atmosphere for a long time. As a result, a tonne of carbon dioxide emitted today will have practically the same impact on climate change whether it originates in London, New York or Mumbai. Whatever the costs are, they are the same no matter where the greenhouse gases are emitted, which is what leads to the presumption in favour of uniform global pricing of any particular greenhouse gas.[3,4] This poses an enormous challenge to the world community to undertake the collective action necessary to impose broadly the same carbon price worldwide and to manage the consequences for the global distribution of income.

3. This presumption is not always valid; it depends on what other market and policy failures have to be taken into account when designing climate change policies. See Section 3.
4. This characteristic means that in one respect, at least, climate change is an easier problem to tackle than many other environmental externalities, where the consequences are heavily dependent on local circumstances.

Different greenhouse gases have different effects on global warming and stay in the atmosphere for different periods, so the costs incurred per tonne of emissions vary according to the gas concerned.[5] But, as these costs can be expressed as a fixed multiple of the costs incurred by a tonne of carbon dioxide (see Box 2.1), the shorthand of referring to 'carbon pricing' has evolved.[6]

The idea of 'internalising' externalities by putting a price on them stretches back to the early 20th century (for example, in Pigou, 1912, 1932). The principle is to balance the harm done (or benefit provided) at the margin by the activity generating the externality with the price charged to (or received by) the business undertaking that activity. The objective is to alter the amount of the activity until this balance is obtained.[7] At the same time, the price changes the pattern of incentives for future investment, consumption and innovation, directing all three away from harmful activities and towards beneficial ones.

Box 2.1 Pricing for different greenhouse gases

The damage done by the emission of a tonne of a greenhouse gas depends on (i) its impact on radiative forcing – the balance between the energy the Earth receives from the Sun and the energy it radiates back into space, (ii) how long it is resident in the atmosphere, and (iii) the damage done by the consequent increase in global temperatures. The impact of different greenhouse gases is usually compared by means of their Global Warming Potential (GWP) over a given period – usually 100 years. The GWP of a gas is the impact that a tonne would have on radiative forcing over the given period relative to a tonne of carbon dioxide. Methane has a GWP over 100 years of 25. Over a shorter period, it has a higher GWP because less of it has broken down into its constituent parts; over 20 years, for example, it has a GWP of 72. A higher price should be placed on emissions of gases with higher GWPs. Although the social cost of emissions depends on the time profile of the stock of greenhouse gases to which it is added and the time profile of its effect on global temperature as well as its GWP, the GWP over a standard period such as 100 years provides a rough and ready way of deriving a price relative to the price for carbon dioxide.

2. Price incentives work

Empirical evidence shows that price changes do change behaviour (see Box 2.2). If in the case of carbon dioxide the price is set uniformly across the economy, these effects will be pervasive, without policy-makers themselves having to identify where there are opportunities for abatement – so pricing economises on the information that policy-makers need. If a government tried to allocate specific greenhouse gas emission quotas to each and every producer of such gases, and those producers had to stick to their quotas exactly – the 'command and control' approach – it is extremely unlikely that the reduction in greenhouse gas emissions would be achieved at least cost, because the government would not have accurate information about how the costs of abatement varied across businesses.

5. About 50% of a carbon dioxide increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years. The average time methane stays in the atmosphere is 12 years, while for nitrous oxide the time is 114 years; some greenhouse gases (e.g. SF6, CF4) stay for thousands of years.
6. The atomic weight of carbon dioxide is 44 while the atomic weight of carbon is 12, so if a price of p per tonne of carbon dioxide is set, the price of a tonne of carbon is (44 x p)/12.
7. In general, in the case of an adverse externality like noise pollution, that does not mean reducing the activity to zero, although there are cases where this is desirable.

Box 2.2 Changing prices does affect demand

Carbon pricing only works as a policy instrument if it succeeds in reducing the demand for greenhouse-gas-intensive activities. The evidence suggests that it is likely to do so, particularly over the longer run and when price changes are expected to persist, because demand does respond to prices.

For example, energy demand has been found to be responsive to changes in energy prices. Indeed, two recent studies suggest that energy demand is more sensitive to prices than many earlier estimates indicated. Agnolucci (2009) investigated energy demand from the British and German industrial sectors and found a long-run price elasticity of demand of -0.64 (i.e. a 10% rise in price, other things being equal, leads in the long run to a fall in energy demand of 6.4%). Adeyemi and Hunt (2007) analysed industrial energy demand across the members of the Organisation for Economic Co-operation and Development (OECD), and found some support for the hypothesis that the response of energy demand to a price change is asymmetric: it depends whether the price increases or decreases. They estimated that the price elasticity of demand for a price increase above its previous maximum is -0.5; for a price increase below its previous maximum it is -0.6; and for a price decrease it is -0.3. That is consistent with the hypothesis put forward by Gately and Huntington (2002) and Huntington (2006) that price increases induce technological improvements designed to economise on the now more expensive energy inputs; if the price falls subsequently, the producer does not usually find it profitable to return to using its previous technology, so energy demand does not increase as much as it fell in the first place.

The demand for petrol provides another example. Brons *et al.* (2008) reviewed studies of the price elasticity of demand for gasoline and found that the mean short-run price elasticity was -0.34 and the mean long-run elasticity was -0.84. Both in the short and the long run, the impact of a change in the gasoline price on demand was mainly driven by responses in fuel efficiency and mileage per car and to a slightly lesser degree by changes in car ownership. That illustrates the point that the adjustment to price increases takes place along several dimensions. Technological changes are induced that lead to greater fuel efficiency but consumer behaviour and purchase patterns are altered too.

Empirical estimates suggest that, even in the long run, a given percentage increase in the price of carbon will bring about a smaller percentage decreases in industrial sector demand for energy and consumers' demand for petrol. One implication is that increases in the carbon price are likely to increase tax revenue, at least until alternative low-carbon technologies become more cost-competitive and displace existing high-carbon ones.

Price changes also affect the direction taken by innovation. Popp (2002) has demonstrated that higher energy prices induce energy-saving technical progress. He concludes that "[m]y results also make clear that simply relying on technological change as a panacea for environmental problems is not enough. There must be some mechanism in place that encourages new innovation." Carbon pricing is one such mechanism. Further evidence using firm-level data is provided by Aghion *et al.* (2010), who found a strong impact of tax-adjusted fuel prices in inducing more technical change in the auto industry, directed towards clean technologies.

3. The challenge of deciding on the correct price

1. The carbon price as the social cost of carbon

The carbon price should reflect the marginal cost of emitting an extra unit of carbon dioxide (or of any other greenhouse gas measured in terms of its carbon dioxide equivalent). Profit-maximising firms will cut back on their greenhouse gas emissions up to the point where the loss of profits from reducing emissions by a further unit – the marginal abatement cost – just starts to get bigger than the price it has to pay for continuing to emit that unit. The problem for policy-makers is how to determine that price, which should in theory be set at the marginal damage cost of a unit of emissions; in other words the present value of the economic cost caused by one extra unit of greenhouse gas while it is in the atmosphere. In the case of carbon dioxide, this marginal damage cost has come to be known as the 'social cost of carbon'.

Estimating the social cost of carbon is, however, a profoundly difficult exercise. The difficulty arises because there are several deep uncertainties in estimating the present value of the economic damage from carbon dioxide while it is in the atmosphere, including uncertainties about the science (the warming resulting from emissions of carbon dioxide and other greenhouse gases and the environmental changes accompanying warming, such as precipitation changes and sea level rise) and uncertainties about the economic impact of climate change. Moreover, these uncertainties are rendered greater by the long residence time of carbon dioxide and other greenhouse gases in the atmosphere, which means that the social cost of carbon today depends on forecasts of greenhouse gas emissions, atmospheric concentrations of greenhouse gases, warming and other climatic changes, and the economic impacts of these over at least two centuries. The slow removal of greenhouse gases from the atmosphere also presents an ethical choice for policy-makers: how much weight should be placed on the impacts of climate change on unborn generations, compared with equivalent impacts today?

The difficulties of assessing all these factors and agreeing on the ethical standpoints taken in so doing have given rise to a large range of estimates of the social cost of carbon and much methodological debate amongst economists (a flavour of the debate is evident in Tol, 2008; Nordhaus, 2008; Ackerman and Stanton, 2010; Dietz, 2011.

2. The carbon price as the marginal cost of abatement

Yet this is not the end of the story. Policies also have to take into account the costs of limiting the risks of human-induced climate change through emissions reductions. That is what helps to pin down the range of greenhouse gas trajectories that are likely to balance over time the uncertain costs of climate change at the margin and the uncertain costs of stopping it – the marginal abatement costs.[8] Just as with the social cost of carbon, many factors influence marginal abatement costs, including the pace of low-carbon innovation likely in the future, the chances of major technological breakthroughs (including finding 'geo-engineering' ways of extracting greenhouse gases from the atmosphere directly) and the ease with which businesses and households can substitute low-carbon products for currently high-carbon ones (in both production and consumption). These factors are likely to have very different effects according to the time horizon over which one is looking.

8. A slightly more formal discussion of how to solve the policy-makers' problem is laid out in Chapter 13 of Stern (2007), which makes the simplifying assumption that the key choice is at what level to stabilise the concentration of greenhouse gases in the atmosphere. To maximise well-being, the expected costs (in terms of well-being sacrificed) over time, suitably discounted, of setting a slightly lower target should equal the expected benefits from the climate change damages thereby averted.

3. A pragmatic approach in the face of uncertainty

Faced with this multiplicity of factors that ought in principle to be taken into account in setting the carbon price, what are policy-makers to do? The argument presented in this Policy Brief is that they should pool their knowledge and understanding of these factors, however incomplete, discuss the issues and make a best guess about the global goal that is likely to result in the highest well-being. As more is learnt about the scientific, economic and ethical uncertainties afflicting climate change, the goal can be periodically adjusted.[9] That goal should allow policy-makers to deduce the appropriate carbon price.

In practice, that is broadly what has happened. A remarkable amount of agreement has been reached about the desirability of limiting the rise in the global mean temperature to 2°C above pre-industrial times. The Conference of the Parties to the United Nations Framework Convention on Climate Change agreed at their 16th session in Cancùn, Mexico, in December 2010 that "deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2°C above pre-industrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity."[10] With this target broadly agreed, climate models can tell us roughly the level of the concentration of greenhouse gases in the atmosphere for which the world should aim. Then economic models can derive paths for the carbon price that set appropriate incentives for cost-effective reductions in emissions consistent with hitting that target.

The argument is that, globally, in reaching a broad consensus about a goal for world collective action, policy-makers have implicitly balanced the social cost of carbon and marginal abatement costs. A lot of horse-trading has been involved, and a lot of the implications may not have been fully understood, but the process has had the advantage of bringing in necessary political and ethical judgements. Given the target, one can explore the likely costs of meeting it and deduce what the marginal abatement costs are likely to be, thereby allowing policy-makers to set an appropriate carbon price to encourage businesses and households to incur this level of costs.[11]

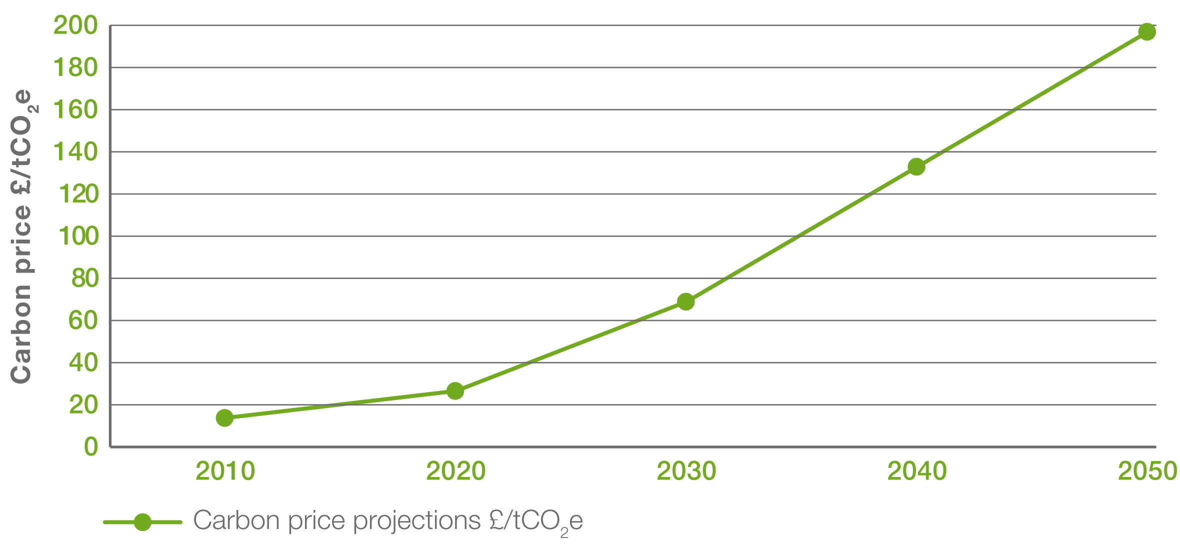
4. How high should the carbon price be?

What does this pragmatic approach suggest about the level and path of carbon prices? There have been many estimates of what price path(s) would incentivise a reduction in emissions big enough to keep the expected temperature increase to 2°C. In general, they have been based on aiming to stabilise the atmospheric concentration of greenhouse gases at or below around 450 parts per million (ppm) of carbon-dioxide-equivalent, although some have focused on carbon dioxide alone.[12]

9. Thus the target should reflect economic and ethical considerations, not only scientific ones.
10. Integrated assessment models that attempt to calculate an optimal ceiling tend to suggest a higher ceiling than 2°C. Critics argue that they do not account properly for uncertainty, the risk of extreme and irreversible changes in climate and climate change impacts that are difficult to quantify. Many countries have also argued that the wisdom of a lower ceiling of 1.5°C should be assessed. There is some ambiguity about what tolerance policy-makers have for exceeding the ceiling and hence what the central expectation should be for the eventual increase in global temperature.
11. This is now broadly the approach recommended by the UK Government for public policy appraisal purposes. The Government emission reduction targets are taken as given and marginal abatement curve projections are used to estimate the cost of reaching them and hence the appropriate price of carbon for project appraisal: see www.decc.gov.uk/en/content/cms/emissions/valuation/valuation.aspx
12. Greenhouse gas concentration measured in terms of carbon-dioxide-equivalent is the concentration of carbon dioxide that would cause the same level of radiative forcing as the actual mix of greenhouse gases in the atmosphere.

To take a few examples: The UK Committee on Climate Change has indicated that prices of £30 per tonne of carbon dioxide in 2020 and £70 in 2030 (in terms of the 2009 overall price level) in the EU Emissions Trading System would be consistent with the UK's own emission reduction goals (see Figure 3.1). The RECIPE project (Edenhofer *et al.*, 2009) used three different models and used an atmospheric concentration of 410 ppm of carbon dioxide only as its '2°C target'; one model suggested a price of around US$13 per tonne in 2020, one indicated a price of around US$44 per tonne, and the model that was most pessimistic about abatement costs produced, a price of around US$280 per tonne (£8.16, £27.61 and £175.71 respectively at today's exchange rate).[13] The ADAM project (Knopf *et al.*, 2009), focusing on a more stringent target of 400 ppm of carbon-dioxide-equivalent, used four different models, three of which suggested carbon prices of around US$40 (£25) per tonne or less for 2020 but one indicated a price of around US$175 per tonne (£109.82). One large-scale US-based model comparison, the Stanford Energy Modeling Forum, was more pessimistic (Clarke *et al.*, 2009); the range of carbon prices for 2020 derived from eight different models was from US$15 per tonne to US$263 per tonne (£9.41 and £165.04 respectively at today's exchange rate), but six further models implied that meeting the target would simply be infeasible.[14]

Figure 3.1 Carbon price projections (£/tCO_2e)



Source: DECC (2010), EC (2010), CCC calculations.

13. Prices measured in terms of the value of the US$ in 2005.
14. The prices here are derived from the versions of these models that assume participation by all countries from the outset and that allow the atmospheric concentration of greenhouse gases to overshoot temporarily the long-run level necessary to meet the temperature increase target.

As far as the time path of carbon prices is concerned, the general conclusion is that the price should rise steadily for many years.[15] According to models in which the greenhouse gas externality is the only one that policy-makers have to worry about, it should increase at a constant rate close to the real rate of interest (that is, after correcting for inflation), as this ensures that the marginal cost of abatement, discounted to the present, is the same in all periods, so that total costs cannot be reduced by shifting around when abatement efforts are carried out.[16] Models have typically adopted a real interest rate of 3% to 5% per year, depending in part on the assumptions they incorporate about the appropriate rate of trade-off of welfare across time.

In practice, there are other externalities relevant to climate change policy-making, such as spill-overs from research and development and economies of scale, which may warrant a higher price in early years to induce more innovation in low-carbon technologies. Later on, if and when new technologies have become cost-competitive, the price incentive is no longer needed according to some models, so the carbon price can be allowed to fall.[17] Macroeconomic feedbacks can also complicate the story. For example, fossil fuel prices may fall if owners of fossil fuel reserves, fearing the success of climate policies, start to exploit the reserves faster to earn returns while they still can. If that were to happen, that would require higher carbon prices than the simple models suggest. They would have to be high enough to drive down the prices of fossil fuels far enough that production beyond the constraints implied by carbon emission targets would be rendered unprofitable. That could require a large fall in fossil fuel prices given the number of potential producers of oil, gas and coal with low long-run marginal extraction costs (e.g. in Iraq, Saudi Arabia, China).[18]

> A carbon price of around £30 per tonne would be appropriate now, which contrasts with the current price in the European Union Emissions Trading Scheme of around £8.55 per tonne at current exchange rates.

These complexities, together with the uncertainties surrounding the parameters used in models of emissions abatement, pose a challenge to policy-makers. They will have to make a 'best guess' of the desired trajectory of the carbon price and then monitor whether emissions reductions and low-carbon innovation are proceeding at roughly the pace anticipated. Some changes in pace may be temporary, so a rapid succession of corrections to the planned trajectory would not make sense. But at some interval – say, every five years – policy-makers should update both their target and their understanding of what carbon price trajectory it will take to reach it.

15. Some models suggest the price should rise monotonically while others suggest that eventually the price should fall (e.g. because cumulative innovation eventually renders low-carbon technologies cheaper than high-carbon ones even without a carbon price, or because a declining carbon tax is necessary to persuade residual fossil fuel suppliers to keep their fuel stocks in the ground until later).
16. More precisely, the carbon price should rise at a rate equal to the real discount rate used by policy-makers plus the rate at which the greenhouse gas concerned leaves the atmosphere via carbon sinks, etc. With the ethical approach to intergenerational income differences adopted in Stern (2007), that would suggest that the carbon price should rise at around 3% per year in real terms (i.e. after allowing for inflation).
17. This pattern is found, for example, in the theoretical work of Acemoglu *et al.* (2009). But few integrated assessment models project a significant decline. It is very difficult to substitute low-carbon technologies in some sectors and they may require a permanently rising carbon price to keep demand down.
18. The story would change if carbon capture and storage became viable at scale for fossil fuel burning.

The UK Committee on Climate Change's thorough review of the outlook for UK abatement is a good starting point for thinking about the appropriate level of UK carbon prices. However, the suggestion of a price of £30 per tonne of CO_2 in 2020 rising to £70 in 2030 implies a faster rate of increase than is likely to be desirable from the point of view of society as a whole – around 9% per year instead of around 3% (see footnote 16). Instead a price of £40 per tonne in 2020 rising to £55 per tonne in 2030 would get closer to equating marginal discounted abatement costs at around the average level implied by the CCC's proposal. Working back to the present day, that would imply that a carbon price of around £30 per tonne would be appropriate now, which contrasts with the current price in the European Union Emissions Trading Scheme (EU ETS) of around €10 per tonne (around £8.55 per tonne at current exchange rates)[19].

That would encourage more energy saving and other changes in behaviour by companies and households in the near term and provide a more powerful incentive for early low-carbon innovation. And it would recognise that there is less advantage in delaying collective action from the vantage point of society as a whole than the steeper price profile implied.

5. The impact of the economic slowdown

How does the fact that most high-income economies are at present suffering from slow growth and unusually high unemployment affect the merits of imposing a high carbon price? In general, environmental policy settings are unlikely to be independent of the business cycle, but the desired adjustment of instruments such as environmental taxes and subsidies depends on the nature of the environmental problem addressed, the source of the business cycle and the extent of rigidities impeding an economy's recovery (Bowen and Stern, 2010).

For example, if aggregate demand is below aggregate potential supply because of the macroeconomic downturn, one would expect the future GDP growth rate in the short to medium term, during the recovery, to be above trend for a while. Compared with a situation where economies were growing at full employment, that would warrant a higher discount rate over the 'catch-up' period and hence a somewhat lower carbon price today (followed by a more rapid rate of increase). But the effect would be small, because the temporary blip in growth would have very little effect on the cumulative stock of greenhouse gases in the atmosphere and hence on the risks from climate change. To the extent that the impact on the level of the trajectory of GDP is to lower it permanently, cumulative greenhouse emissions by any date would be lower and the associated level of risk from climate change damages would be lower, too, also warranting a lower carbon price. But in either of these cases, the impact on the desired carbon price would be less than the drop in price seen in a cap-and-trade system such as the EU ETS, in which emission ceilings are not tightened in response to unexpectedly lower growth.

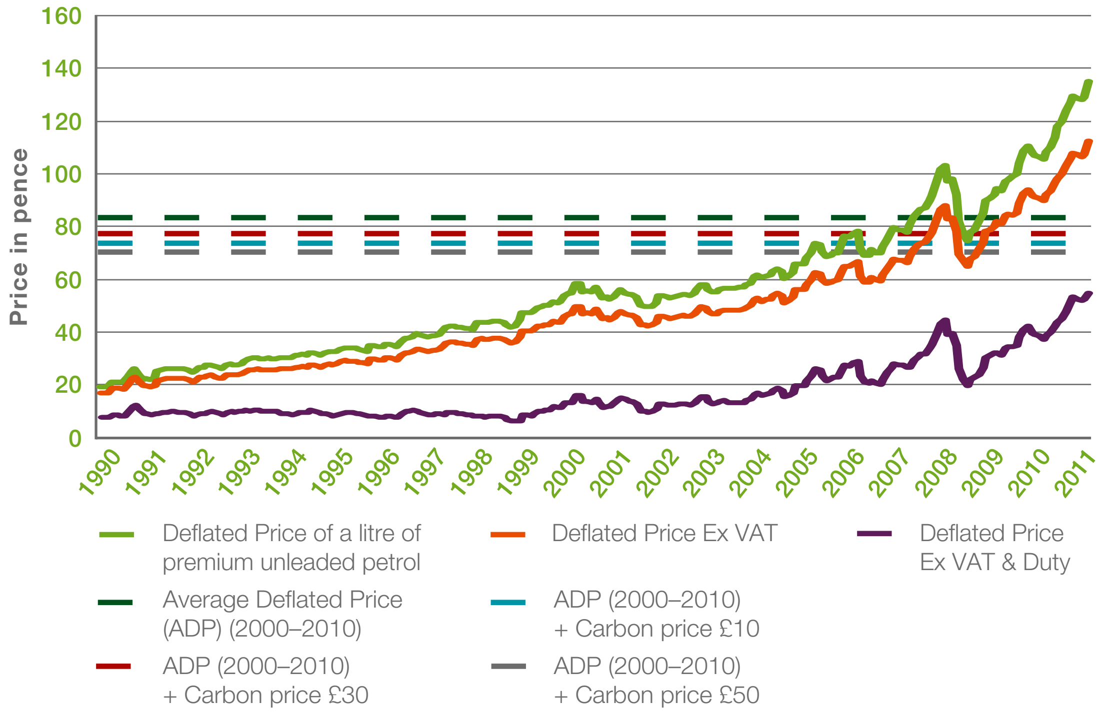
If an economic slowdown hits before carbon pricing has been introduced comprehensively at the desired level, it is still likely to be a good idea to go ahead, even if a slightly lower starting point for the carbon price is warranted. In particular, 'getting relative prices right' and reinforcing the credibility of policy-makers' long-term commitment to decarbonising economies are both likely to encourage private sector investment in low-carbon technologies, buildings, plant and equipment. If other factors inhibiting green investment, such as the large minimum scale of some infrastructure capital needs and the uncertainties surrounding innovative technology, are tackled at the same time, carbon pricing can be part of a strategy to speed up macroeconomic recovery. Carbon pricing would signal a profitable use, in financing green investment, for the increases in planned saving. Such increases characterise the current economic outlook in most advanced economies because many households and governments are struggling to reduce their indebtedness.

19. as of October 2011.

Box 3.1 What impact would a carbon price of £30 per tonne have on prices and incomes?

In the hypothetical case (unlike in the UK) where the price of carbon dioxide was initially zero and was then increased across the economy to £30 per tonne, that would lead to an increase in the price of petrol of about seven pence a litre (and eight pence per litre for diesel), if demand for fuel remained unaltered. In practice, demand would be likely to fall and, with an upward-sloping supply curve for fuel, the price rise would be less than these figures. Figure B3.1a below shows the impact that various carbon price levels would have on a litre of petrol before any such induced reduction in demand, relative to the average real price over the period 2000-2010. The Figure also shows that the historical impact of fuel duty in the UK has been much larger than the impact these carbon prices would have.

Figure B3.1a Components of the real price of petrol per litre and the hypothetical impact of carbon prices

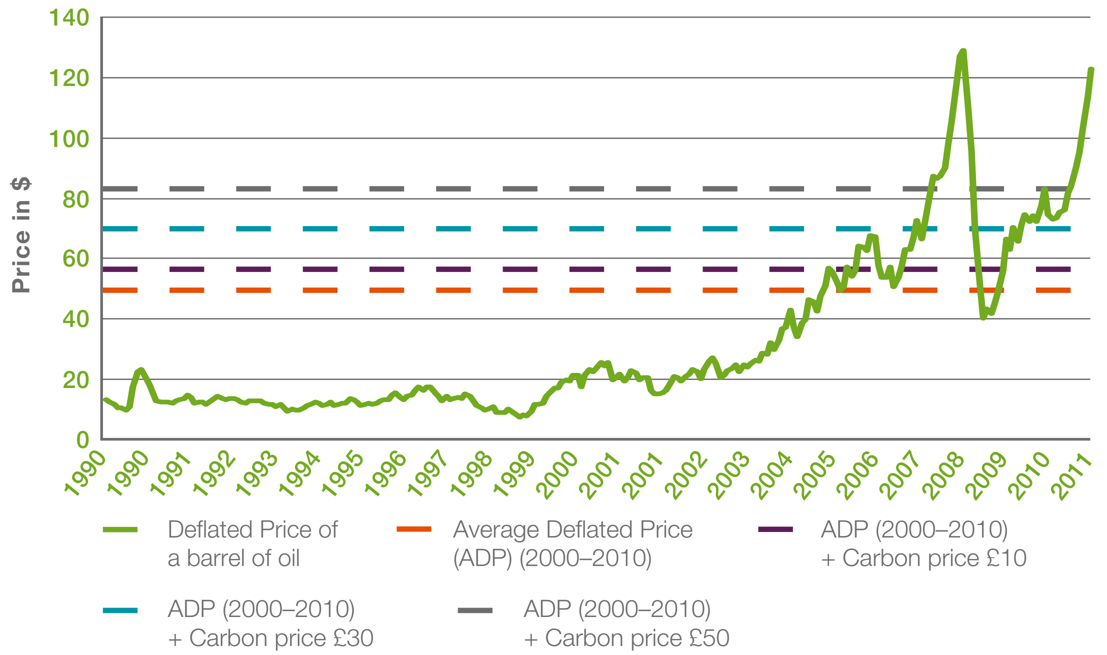


Source: DECC (2011). www.decc.gov.uk/assets/decc/Statistics/source/prices/372-road-fuel-price-statistics-methodology.pdf

Similarly, an increase in the carbon price from zero to £30 per tonne would increase the price of a barrel of crude oil by around £13 (or at current exchange rates around $21). Figure B3.1b shows the historical variation in the real price of a barrel of oil in dollar terms (given that the price of oil is usually quoted in US dollars) and the impact that various levels of the carbon price would have relative to the average oil price over the period 2000-2010. It shows that the variation in the oil price in recent years has been considerably greater than the price change that would be induced by carbon pricing.

However, these figures exaggerate the impact that more consistent and coherent carbon pricing would have on fuel prices because fuels such as petrol are already taxed heavily, in part in order to reduce greenhouse gas emissions. Also, industries subject to the EU ETS already pay a carbon price and other policy instruments such as the Climate Change Levy can be thought of as a form of carbon pricing (see Box 4.1 on the current extent of carbon pricing).

Figure B3.1b Components of the real price of oil per barrel and the hypothetical impact of carbon prices



Source: EPA (2010). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), p. A-58. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-10-006. IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

A move toward a single carbon tax rate across the UK economy might lead to a reduction in some prices and increases in others (depending on what other reasons the authorities have for taxing high-carbon-content goods and services). For example, petrol prices at the pump might go down while domestic heating bills might go up. Spending on domestic heating is the most 'emissions-intensive' part of household expenditure in terms of direct and indirect embodied emissions per pound sterling spent. Fuel for transport is the next most emissions-intensive part of the household budget; spending on personal services (e.g. laundry, hairdressing, etc.) is also fairly emissions-intensive. Clothing is much less so.[20] Direct emissions – from domestic fuel and electricity use and fuel for private cars – accounts for only around one fifth of all the emissions embodied in household expenditure.

The possible impact of carbon pricing on household budgets can be gauged by considering the likely tax take from uniform carbon pricing. Interpolating estimates by the UK Committee on Climate Change, full auctioning of emissions permits at £30 per tonne could raise around £6 billion a year by 2020 from sectors covered by the EU ETS. As these account for around half of UK emissions, about another £6 billion could be raised from other sectors. Imposing VAT at its full rate on domestic fuel could raise an additional £4 billion, giving a total revenue of some £16 billion (about £650 per household). That compares with current receipts from energy taxes of about £32.2 billion. Some current energy taxes could be reduced if carbon pricing were introduced across the board, while a share of the revenues could be spent on improving home energy efficiency for poorer households in energy-inefficient homes.

20. Symons *et al.* (1994) investigated the carbon content of a wide range of commodity groups from the then Family Expenditure Survey. The range of carbon content was large, with a few categories accounting for the majority of the typical carbon footprint. Given relative prices in 1990, and indexing the carbon content of household energy usage per pound sterling spent at 100, the carbon content of spending on petrol and diesel was 43.9, personal services was 20.5, china, glassware, etc was 10.7, food was 3.6, entertainment was 3.5, furniture, floors, etc was 1.8, adult clothing was 0.7 and tobacco products was 0.3.

4. How should a carbon price be introduced?

1. Taxes, quantity controls and hybrid schemes

There are two main methods of establishing a carbon price. First, a government can levy a tax or duty or charge on carbon (or carbon equivalent) content (i.e. the carbon dioxide emissions caused by its production and the production of its inputs, direct and indirect). Second, a government, or some other authority, can establish a quota system in which the aggregate level of emissions covered by the quotas is set equal to the desired level of total emissions and individual quotas are tradable – a cap-and-trade system. In a perfectly competitive market place, the price of a quota of one tonne would be uniform and equal to the marginal abatement cost in the economy, because businesses would balance the cost of cutting emissions by another tonne against the price they have to pay for a quota if they emit that tonne. Direct controls on emissions business by business or sector by sector, without any trading of quotas, would, in contrast, give rise to different marginal abatement costs (implicit carbon prices) across businesses or sectors, which would not be cost effective. The same emissions reductions could be obtained at less cost by having low-cost businesses do more abatement and high-cost businesses do less.

Hybrid schemes with elements of both price and quantity controls have also been proposed (e.g. Pizer, 2002; Hepburn, 2006). Their general principle is to allow some degree of response of both price and quantity to unexpected shocks to marginal abatement costs and economic activity. Both a carbon tax and a quota scheme can raise revenue – as long as, in the latter case, the quotas are auctioned. That provides an attraction to governments at a time of fiscal retrenchment, especially as it entails charging for 'bad' activities (emitting greenhouse gases) rather than 'good' ones (e.g. working).

Governments could also tie down the time profile of the carbon price by announcing a trajectory for the tax rate or, in the traded quota case, by announcing a schedule for future quota allocations.[21] Allowing quotas for different years to be traded in advance can also help to establish an expected time profile. Quotas can also be set for different period lengths (as in McKibbin and Wilcoxen (1997), for example).

2. The role of uncertainties

If uncertainties about climate change damages and abatement costs did not exist, the two basic types of scheme – price-based and quantity-based – would both establish a price and a quantity of emissions in a given period and one could achieve the same desired outcome with either approach. But in an uncertain world, one has to consider the consequences of misjudging the level of damages and abatement costs. If one sets the price, marginal abatement costs are tied down to that level by businesses' responses but one might incur significantly higher- or lower-than-expected emissions. If, however, one sets the quantity of emissions permitted, the costs of achieving the amount of abatement implied could differ from what policy-makers expected.

21. Quota allocations for emissions in future years could also be allocated or auctioned beforehand.

Many economists prefer setting prices rather than setting quantities, because overshooting one year's emissions target will not have much effect on the total stock of greenhouse gases in the atmosphere, and hence on global warming, while forcing businesses to meet a quantity target in any specific year could push up resource costs sharply if policy-makers have misjudged the scope for abatement.[22] But in the long run, given the possibility of tipping points in the climate system and rising risks of catastrophe at higher temperatures, it is still necessary to consider revising the carbon price path if the emissions path deviates persistently from the expected one. That could happen, for example, if it turned out that fossil fuel suppliers did cut their prices in response to carbon pricing.

3. Other pros and cons of different approaches

There are a number of other disputes in the debate over the merits of a carbon tax compared with a cap-and-trade system. For example, one critic of cap-and-trade has argued that "[q]uantity limits are particularly troublesome where targets must adapt to growing economies, differential economic growth, uncertain technological change, and evolving science" (Nordhaus, 2007). This is true but matters less for cost effectiveness if businesses in countries with emission caps are allowed to trade quotas across borders (as they are allowed to do within the EU ETS). In that case, more rapidly growing countries would shoulder more of the burden of adjustment – perhaps a desirable attribute if faster economic growth is reflected in faster per capita income growth (but less so if the growth is driven by faster population growth).

> If a given tax has many purposes, how is one to measure the carbon tax element? This difficulty would be more easily overcome in the context of a comprehensive and systematic approach to setting taxes...

Another issue is the choice of baseline. The natural baseline for a tax is a zero tax whereas the baseline for a cap-and-trade system is usually emissions in a particular year. The choice of dates from which to measure emissions reductions affects how the costs of abatement are shared among countries and so can be the source of much argument. However, an international carbon tax would not escape such arguments as there would still remain the question of whether some countries should be compensated for higher total abatement costs or others compensated because they are poorer and therefore less able to bear any given costs. Also, one has to decide how to treat existing taxes. Does one score existing taxes on energy, for example, as carbon taxes? If a given tax has many purposes (as with the UK motor fuel duty), how is one to measure the carbon tax element? This difficulty would be more easily overcome in the context of a comprehensive and systematic approach to setting taxes, as advocated by the Mirrlees Review (Mirrlees *et al.*, 2011).

22. The formal argument is laid out by Pizer (1997, 1999), building on the insights of Weitzman (1974).

A carbon tax gives certainty over the price of carbon whereas a cap-and-trade system can lead to considerable price volatility, because the inelasticity of the supply of permits in most such schemes combines with inelastic demand for permits in the short run (when plant, equipment and technology are fixed). Such volatility makes corporate planning difficult and is likely to be unattractive to risk-averse investors (although that depends on how correlated the price movements are with other input and output prices). But the volatility can be mitigated by allowing 'banking and borrowing' of quotas across time periods and/or by introducing hybrid schemes in which sharp price movements trigger a change in the authorities' supply of quotas (for instance, Metcalf's 2009 proposal for a 'Responsive Emissions Autonomous Carbon Tax' that combines the short-run price stability of a carbon tax with the long-run certainty of emissions reductions over a control period).

There is also a dispute about whether cap-and-trade schemes are inherently more prone to corruption, because they create rents for those who get their hands on the quotas. But the issue is not clear-cut. Auctioning all quotas removes many of the opportunities to earn rents in a cap-and-trade system, while tax systems can potentially be exploited by corrupt civil servants. Tax systems with cross-border payments to change the pattern of burden-sharing across countries raise the question of what happens to those cross-border flows. But without those flows, worldwide carbon pricing would not be regarded as fair by developing countries. An international cap-and-trade system, or a domestic one that allows firms to buy verifiable emissions reductions abroad, generates such flows automatically. Some see that as an advantage, because it links cross-border payments explicitly to emissions reductions, while others see the 'polluter to polluter' payments as a less transparent way of achieving fair international burden-sharing than straightforward payments to poorer countries. However, cap-and-trade systems may entail more administrative and transactions costs, because of the need to support quota trading.

The continuing debate shows that a consensus on the merits of the alternative systems of putting a price on carbon has not yet been established. Both pure price-based and pure quantity-based systems have their flaws. As far as cost efficiency is concerned, the case for price-based policy instruments in the short run and quantity-based instruments in the long run is persuasive. But the incidence of costs under different systems and the ease of making cross-border payments to ensure fairness also matter. As elements of both systems have been tried in various countries, more empirical research on their effects in practice is not only much needed but also possible. System design is thus another area where learning and refinement of policy tools over time are required.

4. The implications of incomplete global participation in mitigation policies

So far, this discussion of how to introduce a carbon price has concentrated on general principles. In practice, countries' circumstances and governance differ and national conditions may make it easier to use particular types of policy instrument in particular cases. More important, nations are proceeding at different speeds with implementing emissions reductions policies, with few yet implementing comprehensive carbon pricing and many doing little at all. That raises the following question: should a government introduce carbon pricing in its jurisdiction if others do not? Incomplete participation entails free-riding by the non-participants and creates the risk that carbon-intensive activities move from regulated jurisdictions to unregulated ones (i.e. 'pollution havens'), thus reducing the effectiveness of regulation with respect to the ultimate goal, sharp reductions in global emissions, and eroding the country's competitiveness in trade.

This problem of 'carbon leakage' appears to weaken the case for carbon pricing unless it is universally applied. However, in practice the problem does not appear to be acute. Relative energy costs and environmental regulation are only two of the myriad factors that determine firms' location and relative profitability of existing plants. Some carbon-intensive activities, such as electricity generation, produce outputs that are difficult to trade across borders. Empirical work suggests that only for a small part of industry is a carbon price going to make a significant difference to production costs and materially worsen the trade balance (Stern, 2007; Aldy and Pizer, 2009; Carbon Trust, 2010). According to the Pew Center on Climate Change (2008), for example, energy-intensive industries (those for which energy costs are 4% or more of shipped value) consume more than half of the energy used in US manufacturing, while generating only 16% of manufacturing production and 20% of manufacturing employment (less than 1% of total US employment). The Carbon Trust (2010) identified only six sectors in the UK where cost increases are likely to be of significant concern for competitiveness: iron and steel; aluminium; nitrogen fertilisers; cement and lime; basic inorganic chemicals (principally chlorine and alkalines); and pulp and paper. In total, these sectors account for only around 0.5% of UK GDP. And if managers expect implicit or explicit carbon pricing to spread around the world in the near term as the climate challenge becomes more and more acute, they are unlikely to relocate production to 'pollution havens', with all the investment costs that that entails, to exploit a purely temporary policy-induced price differential.

This problem of 'carbon leakage' appears to weaken the case for carbon pricing unless it is universally applied. However, in practice the problem does not appear to be acute.

At present, however, there is considerable uncertainty about the pace at which carbon pricing will evolve and at what levels it will settle. One option for governments that are already convinced of the necessity of strong action on climate change is therefore to consider border pricing adjustments to tackle the competitiveness effects (see Carbon Trust, 2010). That is, governments could levy the carbon price on domestic emissions and the carbon footprint of imports, just as fuel excise duties are charged on both domestically produced and imported fuels. And they could rebate the carbon price levied on the production of goods and services for export. If the carbon pricing does not discriminate between domestic and foreign production, this approach would in principle appear to be compatible with the rules of the World Trade Organisation, although there is still some debate about this. Another approach would be to seek to conclude industry-sector agreements globally or across large regions for the few industries most heavily affected, with an emphasis on sharing best practice in low-carbon technology to make adjustment easier for lower-productivity countries that might otherwise be tempted to compete more aggressively on price.

Box 4.1 How extensive is carbon pricing in practice?

The most extensive carbon pricing scheme is the European Union's Emissions Trading System (EU ETS), which covers more about 12,000 installations that are responsible for around half of the EU's emissions of carbon dioxide and 40% of its total greenhouse gas emissions. The ETS has also been joined by Norway, Iceland and Liechtenstein. But carbon taxes have been levied in Sweden, Finland, Norway and the Netherlands since the 1990s.

There are several other initiatives under way or about to be introduced around the world (detailed information on energy taxes country by country is available from the International Energy Agency). The next largest scheme is the recently legislated Australian system, which will apply a fixed price tax from July 2012 and a trading scheme from July 2015. (See Box 4.4 for more information.) The Chinese National Development and Reform Commission has suggested that trading schemes will begin in the cities of Beijing, Chongqing, Shanghai and Tianjin and the provinces of Hubei and Guangdong before 2013, with a view to introducing a national scheme by 2015. New Zealand has a cap-and-trade scheme and Switzerland has operated a carbon tax (now supplemented by a cap-and-trade scheme) since 2008. Quebec, Alberta and British Columbia all levy carbon taxes. India introduced a carbon tax on coal in 2010. Costa Rica has had a fossil fuel tax for carbon reduction purposes since 1997. In South Korea, targets under a new Greenhouse Gas and Energy Target Management System have been promulgated with the intention of preparing for a national cap-and-trade scheme from the beginning of 2015. In short, there are a large number of existing and proposed carbon pricing initiatives around the world.

In the United States, in contrast, success has been mixed. The American Clean Energy and Security Act of 2009 (the 'Waxman-Markey' Act), which proposed a federal cap-and-trade scheme, passed in the House of Representatives but died in the Senate. Ten US states in the North East operate the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade system for emissions from power plants. The goal is to reduce emissions by 10% by 2018. States sell nearly all emission allowances through auctions and invest the proceeds largely in energy efficiency, renewable energy, and other clean energy technologies, although three states have used revenues to support their general budgets. Given the economic slowdown and the fall in the price of natural gas (which has led to it being substituted extensively for more polluting coal), actual emissions have already fallen some 30% below the cap. And one state, New Jersey, has announced that it will withdraw from participation. The Midwestern Governors' Greenhouse Gas Reduction Accord, which was to have promoted a cap-and-trade scheme from 2012, now appears to be dead. But the state of California has received the go-ahead for a state-wide cap-and-trade scheme to start in 2013. According to 'The Los Angeles Times', by 2016, about US$10 billion in carbon allowances are expected to be traded through the California market, which will be the second-largest carbon market in the world behind that of the EU ETS. Other western states may participate in due course through the Western Climate Initiative.

Box 4.1 (continued)

The carbon prices resulting from these arrangements vary widely. For example, the most recent auction under the RGGI set a floor price of US$1.89 per short ton of carbon dioxide (about $2.08 per tonne or £1.33 per tonne at current exchange rates) while the carbon tax in British Columbia is CAN$25 per tonne (about £15.43 per tonne at current exchange rates – much higher than in the other two Canadian provinces levying a tax). The highest Swiss rate is around €30 per tonne (£25.65 per tonne at current exchange rates) but has a relatively low coverage. Australia is proposing a carbon tax of $23 per tonne (£14.86 per tonne at current exchange rates) from next July. These figures compare with an EU ETS price that has ranged in 2011 between a high of just over €18 (£15.39) per tonne to less than €10 (£8.55) per tonne (with a sharp fall during June).

Figure 4.1a EU ETS price per tonne of carbon dioxide 2005–2011

Source: Data from ICE via Bloomberg.

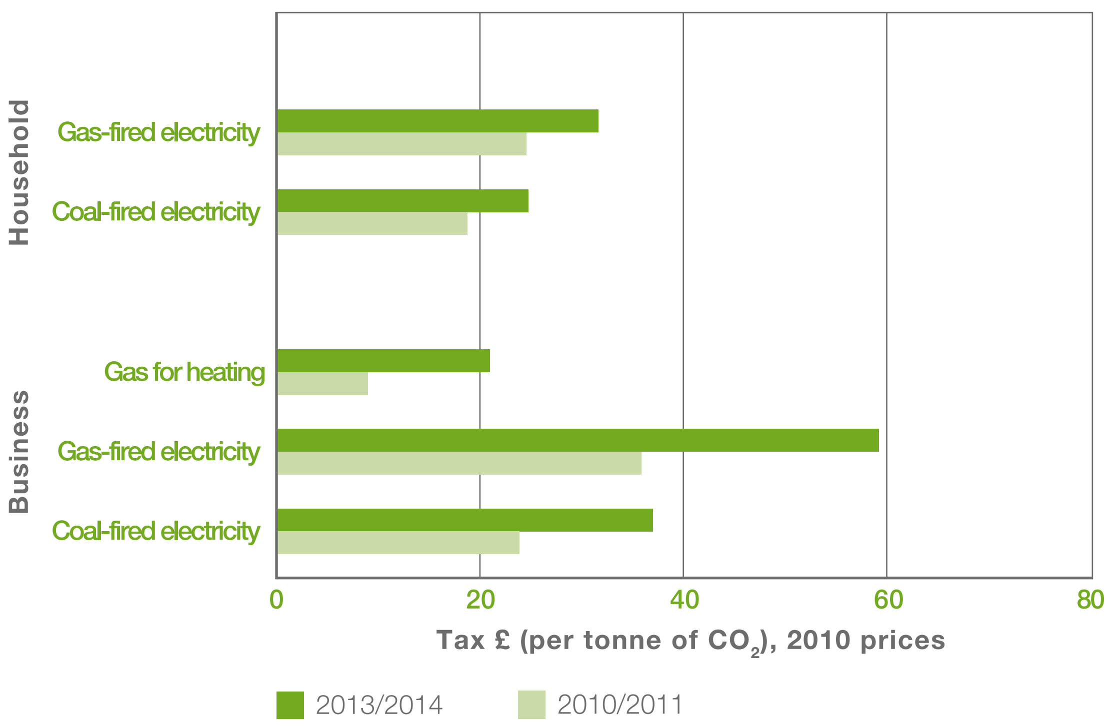
In addition to formal carbon pricing via carbon taxes or cap-and-trade schemes, many governments have levied charges on some types of energy usage. The UK, for example, has imposed a Climate Change Levy since 2001 and an Energy Efficiency Scheme since 2010, in addition to its membership of the EU ETS. And it has been levying excise duties on fossil fuels since 1909 to pursue various objectives, including in recent years emissions reductions.[23] Overlapping schemes can result in considerable variation between the implicit carbon tax on emissions generated in different industrial sectors and different sizes of business, with adverse consequences for cost effectiveness (Fankhauser *et al.*, 2010; Bowen and Rydge, 2011).

23. Petrol duty was introduced in the UK in 1909, the rate being set at 3d (£0.013) per UK gallon.

Box 4.1 (continued)

There is also a semantic issue of whether measures designed to promote the use of low-carbon energy directly (Feed-In Tariffs and Renewables Obligations in the UK), and which also push up the price of carbon-intensive goods and services, should be counted as a form of carbon taxation. On one set of assumptions for the UK, implicit carbon taxes range from zero on the domestic use of natural gas to £43.14 per tonne for gas used to generate electricity for business and £246.33 per tonne for petrol used for transport, although the latter figure assumes that the entire tax on petrol is a carbon tax. Figure 4.1b shows some estimates by the Institute of Fiscal Studies of implicit carbon prices in the UK for electricity and heating, based on information and projections supplied by the Department for Energy and Climate Change and Ofgem. The reduced rate of VAT levied on UK energy use in the home (5% instead of 20%) amounts to a carbon subsidy.

Figure 4.1b Implicit carbon tax



Source: Institute for Fiscal Studies, presentation – indirect and environmental taxes: www.ifs.org.uk/budgets/budget2011/budget2011_al.pdf

It is a challenge for policy-makers in countries pushing forward with carbon-pricing policy to communicate to the public how and why it is a sensible option. The current debate in the UK about increasing energy bills is a case in point, wherein the Department for Energy and Climate Change has failed to explain the principle of carbon pricing in its documentation relating the impact of climate change policies on energy costs. What needs to be explained more clearly is that without carbon pricing the prices of products and services (such as domestic electricity use) that involve emissions of greenhouse gases do not fully reflect the costs associated with the impacts of climate change. This massive market failure imposes costs on those now and in the future who have to deal with the consequences of climate change, and can be corrected by making current polluters pay for emitting greenhouse gases. This is a complex and challenging public message but one which policy-makers must deliver to avoid jeopardising public acceptance of future policy.

Box 4.2 A carbon price floor

The UK Government plans to introduce a carbon price 'floor' for power generators (HM Treasury, 2011). Power generators are subject to the EU ETS regime but do not currently have to pay the UK Climate Change Levy on the fossil fuels that they use. The plan is to charge a Climate Change Levy at a rate sufficient to 'top up' the EU ETS carbon price to reach the carbon floor price trajectory that the government projects will be consistent with the UK's medium-term emissions reductions targets. The introduction of a carbon price floor from 1 April 2013 was announced in the 2011 Budget. The floor will start at around £16 per tonne of carbon dioxide (tCO_2) and follow a linear path to a target of £30/tCO_2 in 2020 (both in 2009 prices). Given projections for the EU ETS price, the floor price will be implemented by a carbon price support rate in 2013–14 of £4.94/tCO_2. Indicative rates for 2014–15 and 2015–16 are £7.28/tCO_2 and £9.86/tCO_2 respectively.

As the Levy rate has to be pre-determined but the EU ETS price varies from day to day according to conditions in the carbon market, the carbon price for generators will remain volatile. The measure will reduce the demand for quotas within the EU ETS, so it will tend to depress the carbon price outside the UK power sector unless the overall EU ETS cap is tightened. If the EU ETS price is below the floor price, EU emission reductions are unlikely to be carried out in the most cost-effective way (IPPR, 2011). But the judgement of the UK Government, and that of the Committee on Climate Change, is that underpinning the EU ETS carbon price will make it much more likely that the UK meets its own emissions targets.

Given the ambition of overall EU emissions reductions targets, the official judgement seems to be that the EU ETS caps are likely to be too loose to be consistent with those targets. That is consistent with the view that the carbon price in the non-ETS sectors is likely to have to be considerably higher than in the EU ETS if UK targets are to be met. It would be more cost effective if the EU ETS had much wider coverage. And emissions reductions targets would be more likely to be achieved if a EU-wide floor were put in place by means of a reserve price at emission quota auctions. Reducing year-to-year volatility in the carbon price in that way would reduce abatement costs over time.

Box 4.3 Case study – The European Union Emissions Trading System

Emissions trading is often seen as superior to command-and-control policy instruments. Markets for environmental resources aggregate information leading to the formation of prices, providing valuable insights about the costs of compliance to environmental regulators. Moreover, market-based instruments ensure that the costs of meeting a given target are minimised. Today, transferable quotas have advanced from being a textbook recommendation to being an important policy instrument. The European Union (EU) Emissions Trading System (ETS) is a remarkable example.

The EU ETS is the largest multinational trading system in the world. It was introduced formally in January 2005 as part of the EU agreement to cut emissions of carbon dioxide through the Kyoto Protocol. Under the Protocol's first commitment period, the EU is due to reduce its greenhouse gas emissions by 8% (relative to 1990 levels) by 2008–2012.

Box 4.3 (continued)

How does it work?

The EU ETS consists of a cap on the total level of emissions allowed from the covered entities, along with permits for emitting greenhouse gases below this cap. These permits are allocated on an annual basis and they can be freely traded. So if a business's emissions are set to fall short of its quota it is free to trade its surplus permits with businesses that need more. In the EU ETS context the first phase of trading was 2005–2007 and the second one, which coincides with the first compliance period of the Kyoto Protocol, is 2008–2012. The third European trading phase will commence in 2013. Installations are allowed to bank and borrow permits within each trading period: they can cover a short position by using previous unused units (banking) or by using permits allocated to following years (borrowing). The scheme allows companies to bank allowances between the current trading period and the next one, but forbids borrowing between trading phases. Capping carbon dioxide emissions at a level lower than that which would take place in a 'business as usual' scenario creates scarcity, thereby generating a positive price for the emissions. An emissions allowance can therefore represent a value to emitters, if the cap is sufficiently strict.

A certain percentage of the allowances in the system are allocated for free, with the percentage differing per sector. In the first two phases of the EU ETS, the absolute majority of the allowances were allocated for free. In the coming third phase (2013–2020), the practice of allocating allowances for free will gradually diminish in favour of auctioning.

If a company reduces its emissions, it can either keep the spare allowances to cover its future needs or sell them to another company that is short on allowances. Furthermore, companies can buy credits through the Joint Implementation (JI) or Clean Development Mechanism (CDM). The former covers emissions abatements in other UNFCCC Annex I countries[24], the latter applies to non-Annex I countries (largely developing countries).[25] The amount of JI or CDM credits that can be bought is limited, and is governed by Directive 2009/29/EC.

24. Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America.
25. Afghanistan, Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Cook Islands, Costa Rica, Cuba, Cyprus, Côte d'Ivoire, Democratic People's Republic of Korea, Democratic Republic of the Congo, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iran (Islamic Republic of), Iraq, Israel, Jamaica, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libya, Madagascar, Malawi, Malaysia, Maldives, Mali, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia (Federated States of), Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, Nicaragua, Niger, Nigeria, Niue, Oman, Pakistan, Palau, Panama, Papua New Guinea, Paraguay , Peru, Philippines, Qatar, Republic of Korea, Republic of Moldova, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Suriname, Swaziland, Syrian Arab Republic, Tajikistan, Thailand, The former Yugoslav Republic of Macedonia, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Tuvalu, Uganda, United Arab Emirates, United Republic of Tanzania, Uruguay, Uzbekistan, Vanuatu, Venezuela (Bolivarian Republic of), Viet Nam, Yemen, Zambia, Zimbabwe.

Box 4.3 (continued)

Who is covered?

Currently, the EU ETS applies mainly to large installations – approximately 12,000 in total – responsible for 40% of EU greenhouse gas emissions. Installations need to report greenhouse gas emissions annually and surrender an equivalent amount of allowances. Conversely, non-compliant installations face a stiff penalty that corresponds to €40 in phase I and €100 in Phases II and III for each tonne of carbon dioxide emitted without an allowance to offset it.

How is the scheme performing?

The EU ETS has been criticised for over-allocation of emissions allowances, price volatility, windfall profits for energy suppliers and failure to deliver significant emissions reductions[26], in addition to the claim that it is unethical.[27]

Other assessments are more positive and highlight that the novelty and scope of the EU ETS have necessitated a 'learning-by-doing' approach, which has resulted in the optimisation of various aspects of the scheme over time.[28] Phase III will feature a number of such optimisations such as the inclusion of the aviation sector and the auctioning of an increased proportion of permits – from around 3% in Phase II to at least 50% in Phase III – to prevent some energy generators reaping repeated windfall profits.

Overall, the EU ETS is delivering emissions reductions. Even the 'learning phase' from 2005–2007, during which prices fell to zero, delivered reductions of 50 to 100 million tonnes each year.[29] However, problems remain with the price level within the scheme as it is questionable whether it provides a sufficient incentive for the low-carbon investment that will be necessary if the EU is to meet its emissions reductions targets. The drivers of the low price include expectations about the future ambition of the EU ETS regime, the surplus permits created by the over-allocation of allowances in Phase I (which has never been properly addressed), and the drop in economic activity that followed the 2008–09 economic crisis. Phase I also saw extreme price volatility. Price volatility has been lower in Phase II.

26. Morris and Worthington (2010).
27. Caney and Hepburn (2011).
28. Ellerman *et al.* (2010).
29. Caney and Hepburn (2011).

Box 4.4 Case study – The Australian Government's carbon pricing policy

Australia's carbon pricing scheme demonstrates the challenges carbon pricing can present for the political economy. Nonetheless, Australia is set to introduce a scheme in 2012 which, in many ways, is as significant as the EU ETS.

The scheme will initially tax carbon dioxide at A$23 per tonne, before making the transition to a trading scheme. It is expected to deliver a large part of Australia's national target to reduce 159 million tonnes of carbon dioxide pollution by 2020, which is equivalent to a 5% reduction below 2000 levels (or approximately 10% below 1990 levels). The scheme will put Australia in a position to ratchet up its ambition to a 25% reduction by 2020 (compared with 1990 levels), which it has said it would agree to depending on future international agreements, as well as other countries' actions and commitments on emissions reductions.[30]

How does the scheme work?

From July 2012, Australia's biggest polluters will pay a fixed price of A$23 (€17 or £15) per tonne of carbon dioxide emitted. Payment will be made through a permit system with unlimited permits available for the first three years, at a rising annual cost at 2.5% above inflation.

In 2015 the scheme will make the transition to emissions trading. From July 2015 the number of permits available will be capped in line with the national target for reducing emissions. An independent Climate Change Authority, modelled on the UK Committee on Climate Change, will provide formal advice on how the scheme is administered, including the setting of caps.

For the first three years of the trading phase there will be a floor price of A$15 to give investors greater certainty. The floor price will be implemented by way of a reserve price at permit auctions, coupled with a fee on imported emissions units to bring their cost up to the floor price.[31] A ceiling price will also be applied to constrain extreme price volatility.

Who is covered?

The Australian scheme will cover about 500 of the country's biggest polluters. This accounts for around 60% of Australia's domestic emissions of greenhouse gases, which is a greater share than is covered by the EU ETS. Emissions from power plants, industrial processes and activities, and waste are regulated. In contrast, heavy road transport, aviation and synthetic greenhouse gases (such as hydrofluorocarbons and sulphur hexafluoride) are to be covered through an equivalent carbon price introduced through the tax system. Agriculture and forestry will be excluded, but are already subject to a domestic offset credit scheme.

30. Australian Government, Department for Climate and Energy Efficiency, National Targets: www.climatechange.gov.au/en/government/reduce/national-targets.aspx
31. Jotzo and Hatfield-Dodds. (2011).

Box 4.4 (continued)

What will be the impacts on international competition?

As part of the scheme, a package of measures has been announced to ensure that emissions-intensive industries are not disadvantaged on the international market. The most vulnerable to international competition will be allocated some free permits as part of their quota. For the most emissions-intensive activities, the free permits will cover 95% of the emissions that would occur, based on levels of output and the industry average for emissions intensity. Those deemed intermediate emissions-intensive activities will receive free permits covering 66% of their emissions. However, this assistance is expected to fall by 1.3% a year, and will be reviewed by Australia's Productivity Commission. The most emissions-intensive coal-fired power plants will also be eligible for financial assistance, but all other emitters will have to buy permits.

What will be the impact on households?

The prospect of increased energy costs as a result of the scheme was central to the public debate prior to its adoption. The impact on households is to be addressed through changes in the income tax system, family payments and welfare. Benefits will be heavily skewed towards households on lower and middle incomes. According to the Australian Government, most individuals below an annual income of A$65,000 will pay $300 less tax, and a two-child family will gain up to $1,200 per year from tax savings and government payments. The Government estimates that two-thirds of households will be fully compensated, or over-compensated, for the rise in their cost of living, even before taking into account changes in consumption because of higher prices for electricity and gas.

What complementary policy mechanisms are being put in place?

Alongside the pricing scheme are new policy initiatives to support investment in renewable energy (including a A$10 billion financing facility), energy efficiency, and land-based carbon sequestration.

5. Carbon pricing and incomes

1. Carbon pricing has consequences for people's real incomes

The case for carbon pricing rests on the way in which it alters relative prices and thus incentives to emit greenhouse gases. However, it also affects people's incomes, businesses' profits and the rents received by fossil fuel owners. By itself, carbon pricing imposes a cost in the near term in order to achieve the benefits of avoided climate change primarily in the medium to long term (just as any investment entails spending on capital instead of consumption now in order to gain benefits in the future). The price has to be set carefully over time to ensure that this trade-off reflects people's ethical views about what weight to give future generations' opportunities.

Carbon pricing also alters relative incomes. For example, by itself, it hits heavy energy users – among both businesses and households – harder than others. It also increases living costs more for people who spend a larger proportion of their income on goods and services that require more energy along their supply chains to produce. The introduction of carbon pricing is designed to engineer a structural change in economies, but structural change rarely comes without adjustment costs, such as relocation expenses, frictional unemployment and additional capital investment needs. There are also changes in relative well-being brought about by the differing incidence of the co-benefits of climate change policies, such as lower particulate pollution. If policies result in different carbon prices for different parts of the economy (as they do in the UK at the moment; Bowen and Rydge, 2011), that will both increase the total cost of emissions abatement and lead to some households arbitrarily bearing a much heavier burden than others, and some industries arbitrarily carrying higher adjustment costs than necessary.

2. Carbon pricing by itself could be regressive via its impact on consumer prices

An assessment of the impact of climate change policies ought to take into account these distributional effects.[32] Unfortunately, the evidence suggests that the impact of carbon pricing on real incomes via consumer prices is regressive – that is, lower-income groups take a proportionately larger hit. This result emerges from studies based on input-output tables (Symons *et al.*, 1994), econometric studies (Barker and Köhler, 1998) and general equilibrium models (Hassett *et al.*, 2009) for developed countries. Lower-income groups in most nations tend to spend a larger proportion of their incomes on energy, although this is not necessarily the case in poorer countries where the least well-off have very poor access to fossil fuel energy. Gough *et al.* (2011) showed that in the UK direct and indirect emissions per capita across households rise less than proportionately with per capita income. The regressivity is particularly acute for emissions associated with domestic energy usage, food and housing.[33]

32. In the terminology of textbook welfare economics, correcting a market failure by internalising an externality only allows an outcome in which no-one is worse off and some are better off (a 'Pareto-superior' outcome) if lump sum transfers are possible. It is only when compensatory payments are possible that considerations of economic efficiency can be separated from considerations of equity.
33. This regressivity underlies concerns about 'fuel poverty.' In the UK, households are deemed to suffer fuel poverty if they need to spend more than 10% of their income on fuel to maintain an adequate level of warmth (usually defined as 21 degrees Celsius for the main living area, and 18 degrees Celsius for other occupied rooms), as well as meeting their other fuel needs (lighting and appliances, cooking and water heating). But what really matters for families is how to balance their spending over a whole range of goods and services, not just fuel. Given the variations in fuel consumption per head, it is possible for households to be in fuel poverty but not poverty per se. It would be more helpful to investigate the extent to which energy requirements and energy prices are responsible for households falling into poverty, defined either by their position in the income distribution or their lack of access to a range of goods and services. Hills (2011) discusses the concept of fuel poverty at greater length.

However, the picture is less clear once the impacts of carbon pricing on wages, transfer payments and the returns on capital are taken into account. Rausch *et al.* (2011) show that, for the United States, impacts on these sources of income completely offset the adverse impact of carbon pricing on the uses of income. That is partly because nearly all transfer payments in the US tax-benefit system are indexed to the general price level, so that they increase automatically when carbon pricing is introduced, pushing up the general price level. Also, given the assumptions made by Rausch *et al.*, they calculate that carbon pricing would tend to depress returns to capital more than wage rates. In developing countries, a carbon price may favour unskilled labour over other factors in production, thus affecting rural and lower-income households less than other people (Yusuf, 2008). Studies, such as those of Gough *et al.* and Rausch *et al.,* which use micro data also show that there is considerable heterogeneity in the tax burden across households, depending on factors such as household size, employment status, region and urbanisation.

3. Adverse distributional effects can be mitigated

Any distributional effects can be mitigated in various ways. First, compensatory payments can be made to groups who would otherwise carry a disproportionate share of the burden. Governments can finance such payments by using revenues raised from charging carbon duties or auctioning emission quotas. There is, however, a danger of revenues from carbon levies and quota auctions being earmarked several times over – for compensating domestic losers from carbon pricing, reducing other distortionary taxes, financing low-carbon research and development, paying for international climate change finance and closing unsustainable fiscal deficits. Policy-makers have to consider carefully the trade-offs among these objectives. Formal earmarking – 'hypothecation' of revenues – is very unlikely to be the best solution given changing and uncertain economic conditions and political preferences.

If compensatory payments are made, they must not reverse the very change in relative prices that carbon pricing is designed to bring about. Thus if one wants to compensate shareholders of energy-intensive firms, that can be done by allocating some free quotas to these firms instead of auctioning them all, while still allowing an emissions trading system to set a price for carbon. People with old, energy-inefficient houses can be given lump-sum payments through the tax-benefit system without giving them rebates on their energy bills. They can also be given help with energy efficiency measures.

Fairness across generations is also a consideration. The current generation can be 'compensated' by future generations in a sense if it bequeaths less plant, equipment and buildings to its successors than it would have done otherwise. That would offset to some degree the fact that the current generation would be leaving a better environment – more 'natural capital' – to their children. Nevertheless, the variety of people's carbon footprints makes it difficult to ensure that there will be no losers at all from carbon pricing. Families in compact, modern, energy-efficient housing in urban areas with good public transport and incomes indexed to inflation are likely to benefit relative to others.

Second, carbon pricing can be accompanied by the use of other policy instruments that generate compensatory benefits. Increased awareness of the risks and costs from climate change has cast light on a range of pre-existing market failures that are now recognised to be more harmful than previously thought, because they stand in the way of a cost-effective transition to a low-carbon economy. Pre-eminent among these market failures is the under-supply of new ideas, research and development because potential innovators cannot capture all the benefits of their innovations. But there are also market failures in the provision of public infrastructure, energy networks and finance. And there are public policy failures such as energy subsidies and unnecessarily distortionary tax systems. Carbon tax revenues, for example, can be used to reduce payroll taxes that discourage labour force participation. If governments are provoked into tackling these market and public policy failures by the threat of climate change, the costs of emissions reductions can be offset to some degree, while also accelerating the transition to a much more sustainable, low-carbon future. This is an important part of the intellectual case for 'green growth' (OECD, 2011; Bowen and Fankhauser, 2011).

6. Why not rely on other policies?

1. Carbon pricing by itself is not enough

Economists have for a long time[34] argued that when there are multiple market and public policy failures, several policy instruments are likely to be needed to tackle them efficiently and cost effectively, with each instrument targeting a particular failure but taking account of its consequences for the rest of the economy.[35] When market failures are present, public policy interventions can, in principle and if properly designed, enhance overall well-being. Policies may also be needed to compensate for the adverse impact of other public actions ('public failures' due, for example, to lobbying or the self-interest or incompetence of policy-makers).

In particular, various market failures afflict innovation (Stern, 2007, Part IV; Jaffe *et al.*, 2005), providing a rationale for carefully designed policy intervention to support research and development and learning-by-doing. First, there are spill-overs from the creation of new knowledge, because its use by its creator does not prevent its use by others (the use of knowledge is 'non-rival'). Second, the benefits to society as a whole from investment in research and development are often much greater than the benefits captured by the businesses undertaking the investment. In other words, the social returns exceed the private returns (Jaffe, 1986; Griliches, 1992), on average by a factor of four (Popp, 2006). Popp argued that the social returns in environmental and energy research and development are comparable to those in other fields. Some approaches to correcting this problem (such as granting unconstrained intellectual property rights) can create monopoly power, which can give rise to a market failure itself. Third, there are externalities from the adoption of new technologies, due to network effects, learning-by-using and learning-by-doing (Jaffe *et al.*, 2003; Edenhofer *et al.*, 2005). These can lead to path dependence of the choice of technologies and the 'lock-in' of high-carbon plant and equipment (Unruh, 2000; Acemoglu *et al.*, 2009). Fourth, the generation of knowledge is affected by uncertainties and asymmetric information (Böhringer *et al.*, 2009). Fifth, market failures in the rest of the economy can have implications for climate change mitigation and renewable energy support. For example, Sjögren (2009) and Guivarch *et al.* (2009) explored the interaction of environmental and labour market imperfections.

2. Carbon pricing is a vital part of the mix

No single policy instrument can correct fully all the relevant market failures. If that is not understood and policy-makers restrict themselves to one instrument, objectives have to be traded off against each other, and the costs of achieving any one objective are higher, because other objectives have to be sacrificed to some extent. Thus, in the context of climate change, an optimal portfolio of policies can achieve greenhouse gas emissions reductions at a significantly lower cost than any single policy – although models suggest that the bulk of the emissions reductions will be brought about by the pricing element of the policy package (Richels and Blanford, 2008; Otto *et al.*, 2008; Fischer, 2008; Fischer and Newell, 2008). Carbon pricing on its own is likely to under-deliver investment in research and development of new technologies (Rosendahl, 2004; Fischer, 2008; IEA, 2011) but innovation policy alone is likely to under-deliver on emissions reductions. Fischer (2008) found that a renewable support policy is much more effective in the context of a carbon price signal. Without carbon pricing, measures that make the energy sector as a whole more efficient make energy use cheaper, generating a 'rebound' effect – an offsetting increase in energy demand.

34. At least since Tinbergen (1952).
35. Market failures are phenomena that prevent private economic agents participating in markets producing by themselves a pattern of production and consumption over space and time in which no-one can be made better off without someone else being made worse off; that is, they prevent a 'Pareto efficient' outcome (Bator, 1958).

In Fischer and Newell's model, the portfolio entails an emissions price, a subsidy for research and development and a renewable generation subsidy. Applying the model to the US electricity industry, they find that the use of their renewable energy support policies allows the emissions price for carbon dioxide to be 36% lower than it would have to be if hitting a specific emissions target relied on the emissions price alone – but a carbon price is still desirable. Also, the authors find that, if only one policy can be used for some reason, emissions pricing is the most cost effective. Grimaud and Lafforgue (2008) also found that the optimal policy portfolio entails both emissions pricing and subsidies to research and development on renewables. If a 'green' subsidy for research and development is impossible, the carbon tax has to be higher; and if the carbon tax is ruled out, the subsidy for research and development has to be higher.

> Carbon pricing on its own is likely to under-deliver investment in research and development of new technologies but innovation policy alone is likely to under-deliver on emissions reductions.

The advantages of using multiple instruments are also evident when mitigation options other than renewable energy, such as carbon capture and storage (CCS), are considered. Gerlagh and van der Zwaan (2006) examined three emissions reductions options – energy savings, transition to low-carbon energy technologies and CCS – and five possible policy instruments – carbon taxes, fossil fuel taxes, renewable energy subsidies, a portfolio standard[36] for the carbon intensity of energy production, and a portfolio standard for the use of renewables. They found that CCS helps to reduce the cost of climate policies but it is still desirable to roll out renewables technologies on a large scale. The most cost-efficient policy is a carbon-intensity portfolio standard combined with a carbon tax, the revenues of which are recycled to support renewables deployment.

The path dependency of technological choices and its implications for climate policy have also been analysed. Schmidt and Marschinski (2009) noted that new technologies (e.g. mobile telephones) have often reached a stage where economies of scale in production, and the incentive of rising returns to research and development as output rises, have started to reduce costs fast enough to permit very rapid diffusion throughout the economy. Using a model of energy generation in which research and development responds positively to rising returns and there are several market failures, they found that multiple equilibria are possible, and policy instruments have to be used to push the world economy towards an equilibrium with high renewable energy use. The optimal policy mix entails a tax on fossil energy (a carbon tax), a research and development subsidy, an investment subsidy and a fee for employing initial public knowledge (equal to the patent fee charged for private knowledge).

36. A 'portfolio standard' mandates that the portfolio of processes used to generate energy does not exceed a certain carbon intensity or comprises some particular proportions of renewable energy sources.

Acemoglu *et al.* (2009) examined technical change that responds to the relative incentives across industry sectors, in a growth model with environmental constraints and limited resources. They showed that carbon taxes as well as taxes on fossil fuel energy production and innovation (or subsidies to clean energy production and innovation) are required. If renewables and fossil fuels are sufficiently substitutable as inputs to production, fossil fuel energy production and innovation only have to be taxed temporarily, until the increased incentive for research and development in renewables has reduced their production costs enough to switch the economy on to a low-emissions growth path.

Policy-makers must avoid 'own goals' such as overt and hidden fossil fuel subsidies, poor or unco-ordinated implementation of different policies and regulation by resource-intensive 'command and control' methods.

Just as a mix of policies that excludes carbon pricing is insufficient to manage the threat of climate change, a mix that ignores the market failures in the provision of energy system infrastructure and in the building industry's approach to energy efficiency is inadequate. Policy-makers need to consider how to overcome the difficulties faced by the private sector in financing large-scale energy projects, due to the asymmetry in knowledge about the costs, risks and benefits between project owners and financiers. They also need to provide incentives for the creation and growth of new energy (and possibly carbon dioxide) distribution networks, given that potential joiners would not normally factor in the benefit of their joining to other businesses (a particularly important issue for networks in their infancy). And they can play a major part in providing information about energy efficiency opportunities to buildings' tenants and owners, encouraging them to monitor their energy use. Finally, policy-makers must avoid 'own goals' such as overt and hidden fossil fuel subsidies, poor or unco-ordinated implementation of different policies and regulation by resource-intensive 'command and control' methods.[37]

37. Another market failure may arise with respect to 'energy security'. Private suppliers of energy may not give sufficient weight to the costs to a nation if energy supplies are disrupted, because the suppliers would not bear all of these costs. But the textbook economist's response would be to look for policy instruments attuned to this particular problem, such as support for larger, more robust, international energy distribution networks (echoing the arguments for the internet as a means of reducing the risk of interruptions to the supply of communications). It should also be noted that energy security is not a strong argument for clean energy in countries such as China, India and Poland, which have large domestic reserves of fossil fuels.

7. Conclusions

The economics of climate change is a rapidly evolving subject but on one point it is clear: to reduce greenhouse gas emissions sharply in a cost-effective way, a uniform global carbon price (and prices on other greenhouse gases in proportion to their warming potential) would be desirable. It would act as a pervasive encouragement for businesses to adjust their investment, their mix of inputs and their innovatory activities away from greenhouse-gas-intensive technologies, and for consumers to adjust their spending patterns away from high-carbon products. There is less of a consensus among economists about the appropriate level of the carbon price today and about the precise way in which a price should be introduced. To keep the expected global temperature increase to no more than 2°C, it would be sensible to move rapidly towards a price of the order of £30 per tonne of carbon dioxide in the UK while taking due account of structural adjustment costs. In the absence of a strong binding international agreement, it is nevertheless important that policy-makers here and abroad move gradually towards a broadly equivalent carbon price across sectors so that the burden of adjustment costs is spread efficiently across economies and thus minimised.

Policy-makers will have to be ready to adjust their policies and the resulting price trajectory over time as they learn about the costs of emissions reductions, the risks of climate change and the pace of low-carbon innovation. It is important that these adjustments are signalled well in advance to the private sector, and done in a way that preserves policy credibility (Helm *et al.*, 2003). They will also have to consider the distributional consequences of carbon pricing. The potential revenue from charges on carbon or from emissions quota auctions in cap-and-trade schemes allows them to offset to some extent the incidence of carbon pricing on the disadvantaged. The consequences for competitiveness have to be assessed too, although they seem unlikely to be substantial. However, the possibility of switching to levying a carbon price on the embedded carbon in all domestically consumed goods and services, whether produced domestically or abroad – perhaps by means of border tax adjustments – should be considered as a policy option.

Other policies are needed too, particularly to promote innovation and appropriate infrastructure investment, but cannot be relied upon by themselves to bring about the necessary reductions in emissions. Carbon pricing is crucial.

A major challenge for policy-makers is to communicate to business and the public why carbon pricing is a sensible option. To do this, policy-makers must explain very clearly the nature of the market failure that means the current prices of goods and services do not fully reflect the expected costs of climate change impacts which will be borne by future generations. A failure to explain the rationale for carbon pricing in terms of the 'polluter pays' principle could jeopardise public acceptance and support.

References

Acemoglu, D., Aghion, P., Bursztyn, L. and Hemous, D. 2009. The environment and directed technical change. NBER Working Paper 15451, NBER, Cambridge, MA, October.

Ackerman, F. and Stanton, E.A. 2010. *The social cost of carbon*. A Report for the Economics for Equity and the Environment Network, Stockholm Environment Institute – US Center, April.

Adeyemi, O.I. and Hunt, L.C. 2007. Modelling OECD industrial energy demand: asymmetric price responses and technical change. *Energy Economics*, v. 29, p. 693–709.

Aghion, P. Dechezlepretre, A., Hemous, D., Martin, R. and Van Reenen, J. 2010. Carbon taxes, path dependency and directed technical change: evidence from the auto industry. Paper presented at the EAERE conference, Rome, 2011.

Agnolucci, P. 2009. The energy demand in the British and German industrial sectors: Heterogeneity and common factors. *Energy Economics*, v. 31, p. 175–187.

Aldy, J.E. and Pizer, W.A. 2009. *The competitiveness impacts of climate change mitigation policies*, Resources for the Future for the Pew Center on Global Climate Change, Washington DC.

Barker, T. and Köhler, J. 1998. Equity and ecotax reform in the EU: achieving a 10 per cent reduction in CO_2 emissions using excise duties. *Fiscal Studies*. v. 19 (4), p. 375–402.

Bator, F.M. 1958. The anatomy of market failure. *Quarterly Journal of Economics*, v. 72 (3), p. 351–379.

Böhringer, C., Mennel, T.P. and Rutherford, T.F. 2009. Technological change and uncertainty in Environmental Economics. *Energy Economics*, v. 31, p. S1–S3.

Bowen, A. and Fankhauser, S. 2011. The green growth narrative: paradigm shift or just spin? *Global environmental change*, v. 21 (4), p. 1157–1159.

Bowen, A. and Rydge, J. 2011. Climate-change policy in the United Kingdom. *OECD Economics Department Working Papers*, No. 886, OECD Publishing. http://dx.doi.org/10.1787/5kg6qdx6b5q6-en

Bowen, A. and Stern, N. 2010. Environmental policy and the economic downturn. *Oxford Review of Economic Policy*, v. 26, p. 137–163.

Brons, M., Nijkamp, P., Pels, E. and Rietveld, P. 2008. A meta-analysis of the price elasticity of gasoline demand. A SUR approach. *Energy Economics*, v. 30, p. 2105–2122.

Caney, S. and Hepburn, C. 2011. Carbon trading: unethical, unjust and ineffective? Royal Institute of Philosophy Supplement, v. 69, p. 201–234.

Carbon Trust. 2010. *Tackling carbon leakage*. Carbon Trust, London, March.

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S. and Tavoni, M. 2009. International climate policy architectures: Overview of the EMF 22 international scenarios. *Energy Economics*, v. 31, Special Supplement 2, p S64–S81.

Committee on Climate Change 2011. Meeting Carbon Budgets – 3rd progress report to Parliament. Committee on Climate Change, London.

Dietz, S. 2011. The treatment of risk and uncertainty in the US social cost of carbon for regulatory impact analysis. *Economics* (e-journal), Discussion Paper No. 2011–30.

Ellerman, D., Convery, F.J. and Perthius, C. 2010. *Pricing Carbon: the European Union Emissions Trading Scheme*, Cambridge University Press, Cambridge.

Edenhofer, O., Bauer, N. and Kriegler, E. 2005. The impact of technological change on climate protection and welfare: insights from the model MIND. *Ecological Economics*, v. 54, p. 277–292.

Edenhofer, O., Carraro, C., Hourcade, J.-C., Neuhoff, K., Luderer, G., Flachsland, C., Jakob, M., Popp, M., Steckel, J., Strohschein, J., Bauer, N., Brunner, S., Leimbach, M., Lotze-Campen, H., Bosetti, V., de Cian, E., Tavoni, M., Sassi, O., Waisman, H., Crassous-Doerfler, R., Monjon, S., Dröge, S., van Essen, H., del Río, P. and Türk, A. 2009. *The Economics of Decarbonization*. Report of the RECIPE project, Potsdam Institute for Climate Impact Research, Potsdam.

Fankhauser, S., Hepburn, C. and Park, J. 2010. Combining multiple climate policy instruments: how not to do it. *Climate Change Economics*, v. 1 (3), p. 209–225.

Fischer, C. 2008. Emissions pricing, spillovers, and public investment in environmentally friendly technologies. *Energy Economics*, v. 30 (2), p. 487–502.

Fischer, C. and Newell, R.G. 2008. Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management*, v. 55, p. 142–162.

Gerlagh, R. and Van der Zwaan, B. 2006. Options and instruments for a deep cut in CO_2 emissions: carbon dioxide capture or renewables, taxes or subsidies? *Energy Journal*, v. 27 (3), p. 25–48.

Gough, I., Abdallah, S., Johnson, V., Ryan-Collins, J. and Smith, C. 2011. The distribution of total greenhouse gas emissions by households in the UK, and some implications for social policy. CASE paper No. 152, Centre for Analysis of Social Exclusion, Suntory and Toyota Centres for Economics and Related Disciplines, London School of Economics and Political Science, July.

Gately, D. and Huntington, H.G. 2002. The asymmetric effects of changes in price and income on energy and oil demand. *Energy Journal*, v. 23 (1), p. 19–56.

Griliches, Z. 1992. The search for R&D spillovers. *Scandinavian Journal of Economics*, v. 94, p. S29–S47.

Grimaud, A. and Lafforgue, G. 2008. Climate change mitigation policies: are R&D subsidies preferable to a carbon tax?, LERNA Working Paper 08.31.275, University of Toulouse.

Guivarch, C., Crassous, R., Sassi, O. and Hallegatte, S. 2009. The costs of climate policies in a second best world with labour market imperfections. CIRED Working Paper 16–2009, September.

Hassett, K.A., Mathur, A. and Metcalf, G.E. 2009. The incidence of a U.S. carbon tax: a lifetime and regional analysis. *The Energy Journal*, v. 30, p. 157–179.

Hepburn, C. 2006. Regulation by prices, quantities, or both: a review of instrument choice. *Oxford Review of Economic Policy*, v. 22 (2), p. 226–247.

Helm, D., Hepburn, C. and Mash, R. 2003. Credible carbon policy. *Oxford Review of Economic Policy*, v. 19 (3), p. 438–50.

HM Treasury 2011. *Carbon price floor consultation: the Government response*, March.

Huntington, H.G. 2006. A note on price asymmetry as induced technical change. *The Energy Journal*, v. 27 (3), p. 1–7.

Mirrlees, J., Adam, S., Besley, T., Blundell, R., Bond, S., Chote, R., Gammie, M., Johnson, P., Myles, G. and Poterba, J. 2011. *Tax by design: the Mirrlees review*. Oxford University Press, September.

Jotzo, F. and Hatfield-Dodds, S. 2011. Price floors in emissions trading to reduce policy related investment risks: an Australian view. CCEP Working Papers 1105, Centre for Climate Economics & Policy, Crawford School, Australian National University.

Morris, D. and Worthington, B. 2010. Cap or trap? How the EU ETS risks locking-in carbon emissions, Sandbag Climate Campaign.
www.sandbag.org.uk/site_media/pdfs/reports/caportrap.pdf

International Energy Agency. 2011. *Energy efficiency policy and carbon pricing*, Information Paper, Energy Efficiency Series, International Energy Agency, Paris, August.

Institute for Public Policy Research. 2011. *Hot air: the carbon price floor in the UK*. Institute for Public Policy Research, London, June.

Jaffe, A.B. 1986. Technological opportunity and spillover of R&D: evidence from firms' patents, profits, and market value. *American Economic Review*, v. 76, p. 984–1001.

Jaffe, A.B., Newell, R.G. and Stavins, R.N. 2003: Technological change and the environment, Chapter 11. In: Mäler, K.-G. and Vincent, J.R. (Eds), *Handbook of Environmental Economics*, v. 1. Elsevier Science, Amsterdam, p. 461–516.

Jaffe, A.B., Newell, R.G. and Stavins, R.N. 2005. A tale of two market failures: technology and environmental policy. *Ecological Economics*, v. 54, p. 164–174.

Knopf, B., Edenhofer, O. and others. 2009. The economics of low stabilisation: implications for technological change and policy. In: Hulme, M. and Neufeldt, H. (Eds), *Making climate change work for us*. Cambridge University press, Cambridge.

McKibbin, W. and Wilcoxen, P. 1997. A better way to slow global climate change. Brookings Policy Brief No. 17, June.

Metcalf, G. 2009. Cost containment in climate change policy: alternative approaches to mitigating price volatility. NBER Working Paper No. 15125, July.

Nordhaus, W. D. 2007. To tax or not to tax: alternative approaches to slowing global warming. *Review of Environmental Economics and Policy*, v. 1, p. 26–44.

Nordhaus, W.D. 2008. *A question of balance: weighing the options on global warming policies*. Yale University Press, New Haven.

Organisation for Economic Co-operation and Development. 2011. *Towards green growth*, Organisation for Economic Co-operation and Development, Paris, May.

Otto, V.M., Loschel, A. and Reilly, J. 2008. Directed technical change and differentiation of climate policy. *Energy Economics*, v. 30 (6), p. 2855–2878.

Pew Center on Climate Change. 2008. *Addressing competitiveness in U climate change policy*. Congressional Brief. Pew Center on Climate Change, Washington DC, Fall.

Pigou, A.C. 1912. *Wealth and Welfare*. Macmillan, London.

Pigou, A.C. 1932. *The Economics of Welfare*. 4th edition, Macmillan, London.

Pizer, W.A. 1997. *Prices vs. quantities revisited: the case of climate change.* Discussion Paper dp-98-02, Resources For the Future.

Pizer, W.A. 1999. The optimal choice of climate change policy in the presence of uncertainty. Resource and Energy Economics, v. 21 (3–4), p. 255–287.

Pizer, W.A. 2002. Combining price and quantity controls to mitigate global climate change. Journal of Public Economics, v. 85 (3), p. 409–434.

Popp, D. 2002. Induced innovation and energy prices. *American Economic Review*, v. 92 (1), p. 160–180.

Popp, D. 2006. Innovation in climate policy models: implementing lessons from the economics of R&D. *Energy Economics*, v. 28, p. 596–609.

Rausch, S., Metcalf, G.E. and Reilly, J.M. 2011. Distributional impacts of carbon pricing: a general equilibrium approach with micro-data for households. MIT Joint Program on the Science and Policy of Global Change, Report No. 202, July.

Richels, R.G. and Blanford, G.J. 2008. The value of technological advance in decarbonising the US economy. *Energy Economics*, v. 30 (6), p. 2930–2946.

Rosendahl, K.E. 2004. Cost-effective environmental policy: implications of induced technological change. *Journal of Environmental Economics and Management*, v. 48, p. 1099–1121.

Schmidt, R.C. and Marschinski, R. 2009. A model of technological breakthrough in the renewable energy sector. *Ecological Economics*, doi 10.1016/j.ecolecon.2009.08.023.

Sjögren, T. 2009. Optimal taxation and environmental policy in a decentralized economic federation with environmental and labor market externalities. Umeå Economic Studies 785, Department of Economics, Umeå University.

Stern, N. 2007. *The Economics of Climate Change – The Stern Review*. Cambridge University Press, Cambridge, 692 p.

Symons, E., Proops, J. and Gay, P. 1994. Carbon taxes, consumer demand and carbon dioxide emissions: a simulation analysis for the UK. *Fiscal Studies*, v. 15, no. 2, p. 19–43.

Tol, R. 2008. The social cost of carbon: trends, outliers and catastrophes. *Economics* (e-journal), v. 2.

Unruh, G.C. 2000. Understanding carbon lock-in. *Energy Policy*, v. 28 (12), p. 817–830.

Weitzman, M. L. 1974. Prices vs. quantities. *Review of Economic Studies*, v. 41 (4), p. 477–491.

Yusuf, A. 2008. The distributional impact of environmental policy: the case of carbon tax and energy pricing reform in Indonesia. Economy and Environment Program for Southeast Asia, Research Report 1.