10 Macroeconomic Models of Costs

Key Messages

Broader behavioural modelling exercises suggest a wide range of costs of climate-change mitigation and abatement, mostly lying in the range –2 to +5% of annual GDP by 2050 for a variety of stabilisation paths. These capture a range of factors, including the shift away from carbon-intensive goods and services throughout economies as carbon prices rise, but differ widely in their assumptions about technologies and costs.

Overall, the expected annual cost of achieving emissions reductions, consistent with an emissions trajectory leading to stabilisation at around 500-550ppm CO_2e, is likely to be around 1% of GDP by 2050, with a range of +/- 3%, reflecting uncertainties over the scale of mitigation required, the pace of technological innovation and the degree of policy flexibility**.**

Costs are likely to rise significantly as mitigation efforts become more ambitious or sudden, suggesting that efforts to reduce emissions rapidly are likely to be very costly.

The models arriving at the higher cost estimates for a given stabilisation path make assumptions about technological progress that are pessimistic by historical standards and improbable given the cost reductions in low-emissions technologies likely to take place as their use is scaled up.

Flexibility over the sector, technology, location, timing and type of emissions reductions is important in keeping costs down. By focusing mainly on energy and mainly on CO_2, many of the model exercises overlook some low-cost abatement opportunities and are likely to over-estimate costs. Spreading the mitigation effort widely across sectors and countries will help to ensure that emissions are reduced where is it cheapest to do so, making policy cost-effective.

While cost estimates in these ranges are not trivial, they are also not high enough seriously to compromise the world's future standard of living – unlike climate change itself, which, if left unchecked, could pose much greater threats to growth (see Chapter 6). An annual cost rising to 1% of GDP by 2050 poses little threat to standards of living, given that economic output in the OECD countries is likely to rise in real terms by over 200% by then, and in developing regions as a whole by 400% or more.

How far costs are kept down will depend on the design and application of policy regimes in allowing for 'what', 'where' and 'when' flexibility in seeking low-cost approaches. Action will be required to bring forward low-GHG technologies, while giving the private sector a clear signal of the long-term policy environment (see Part IV).

Well-formulated policies with global reach and flexibility across sectors will allow strong economic growth to be sustained in both developed and developing countries, while making deep cuts in emissions.

10.1 Introduction

The previous chapter calculated the price impact of increasing fossil-fuel costs on the economy and then developed a detailed technology-based estimation approach, in which the costs of a full range of low GHG technologies were compared with fossil fuels for a path with strong carbon emissions abatement. A low-carbon economy with manageable costs is possible, but will require a portfolio of technologies to be developed. Overall, the economy-wide costs were found to be around 1% of GDP, though there remains a wide range reflecting uncertainty over future innovation rates and future fossil-fuel extraction costs and prices.

The focus of this chapter is a comparison of more detailed behavioural modelling exercises, drawing on a comparative analysis of international modelling studies. Different models have been tailored to tackle a range of different questions in estimating the total global costs of moving to a low-GHG economy. Section 10.2 highlights the results from these key models. The models impose a variety of assumptions, which are identified in section 10.3 and reflect uncertainty about the real world and differences of view about the appropriate model structure and, in turn, yield a range of costs estimates. The section investigates the degree to which specific model structures and characteristics affect cost estimates, in order to draw conclusions about which estimates are the most plausible and what factors in the real world are likely to influence them. Section 10.4 puts these estimated costs into a global perspective. There are also important questions about how these costs will be distributed, winners and losers, and the implications of countries moving at different speeds. These are examined further in Chapter 11.

The inter-model comparison reaffirms the conclusion that climate-change mitigation is technically and economically feasible with mid-century costs most likely to be around 1% of GDP, +/- 3%.

Nevertheless, the full range of cost estimates in the broader studies is even wider. This reflects the greater number of uncertainties in the more detailed studies, not only over future costs and the treatment of innovation, but also over the behaviour of producers and consumers and the degree of policy flexibility across the globe. Any models that attempt to replicate consumer and producer behaviours over decades must be highly speculative. Particular aspects can drive particular results especially if they are 'run forward' into the distant future. Such are the difficulties of analysing issues that affect millions of people over long time horizons. However, such modelling exercises are essential, and the presence of such a broad and growing range of studies makes it possible to draw judgements on what are the key assumptions.

10.2 Costs of emissions-saving measures: results from other models

A broader assessment of mitigation costs requires a thorough modelling of consumer and producer behaviour, as well as the cost and choice of low-GHG technologies.

There have been a number of modelling exercises that attempt to determine equilibrium allocations of energy and non-energy emissions, costs and prices (including carbon prices), consistent with changing behaviour by firms and households. The cost estimates that emerge from these models depend on the assumptions that drive key relationships, such as the assumed ease with which consumers and producers can substitute into low-GHG activities, the degree of foresight in making investment decisions and the role of technology in the evolution of costs.

To estimate how costs can be kept as low as possible, models should cover a broad range of sectors and gases, as mitigation can take many forms, including land-use and industrial-process emissions.

Most models, however, are restricted to estimating the cost of altered fossil-fuel combustion applied mostly to carbon, as this reduces model complexity. Although fossil-fuel combustion accounts for more than three-quarters of developed economies' carbon emissions, this simplifying assumption will tend to over-estimate costs, as many low-cost mitigation opportunities in other sectors are left out (for example, energy efficiency, non-CO_2 emissions mitigation in general, and reduced emissions from deforestation; see Chapter 9). Some of the most up-to-date and extensive comparisons surveyed in this section include:

- Stanford University's Energy Modelling Forum (EMF);
- the meta-analysis study by Fischer and Morgenstern (Resources For the Future (2005));
- the International Energy Agency accelerated technology scenarios;
- the IPCC survey of modelling results;
- the Innovation Modelling Comparison Project (IMCP);
- the Meta-Analysis of IMCP model projections by Barker et al (2006);
- the draft US CCSP Synthesis and Assessment of "Scenarios of Greenhouse-Gas Emissions and Atmospheric Concentrations and Review of Integrated Scenario Development and Application" (June 2006).

The wide range of model results reflects the design of the models and their choice of assumptions, which itself reflects the uncertainties and differing approaches inherent in projecting the future.

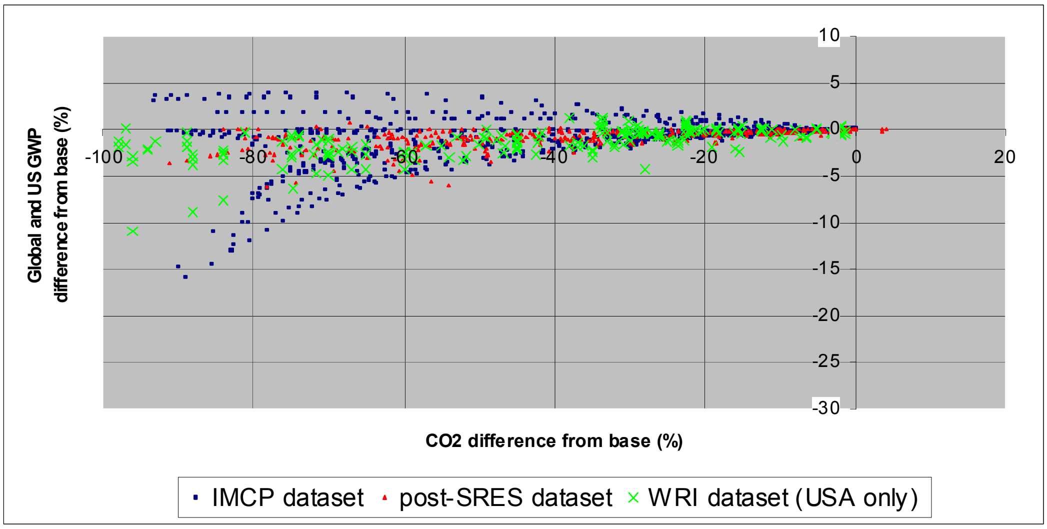
Figure 10.1 uses Barker's combined three-model dataset to show the reduction in annual CO_2 emissions from the baseline and the associated changes in world GDP. Although most of the model estimates for 2050 are clustered in the –2 to 5% of GDP loss in the final-year cost range, these costs depend on a range of assumptions. The full range of estimates drawn from a variety of stabilisation paths and years extends from –4% of GDP (that is, net gains) to +15% of GDP costs. A notable feature, examined in more detail below, is the greater-than-proportionate increase in costs to any rise in the amount of mitigation.

This variation in cost estimates is driven by a diversity of characteristics in individual models. To take two examples, the AIM model shows a marked rise in costs towards 2100, reflecting the use of only one option – energy conservation – being induced by climate policy, so that costs rise substantially as this option becomes exhausted. At the opposite extreme, the E3MG global econometric model assumes market failures due to increasing returns and unemployed resources in the base case. This means that additional energy-sector investment, and associated innovation driven by stabilisation constraints, act to *increase* world GDP. The fact that there is such a broad range of studies and assumptions is welcome, making it possible to use meta-analysis[1] to determine what factors drive the results.

[1] In statistics, a meta-analysis combines the results of several studies that tackle a set of related research hypotheses. In order to overcome the problem of reduced statistical power in individual studies with small sample sizes, analysing the results from a group of studies can allow more accurate data analysis.

Figure 10.1 Scatter plot of model cost projections

Costs of CO_2 emissions reductions as a fraction of GDP against level of reduction



Source: Barker et al. (2006). *Note: GWP should read GDP.*

Model comparison exercises help to identify the reasons why the results vary.

To make sense of the growing range of estimates generated, model comparison exercises have attempted to synthesise the main findings of these models. This has helped to make more transparent the differences between the assumptions in different models. A meta-analysis of leading model simulations, undertaken for the Stern Review by Terry Barker[2], shows that some of the higher cost estimates come from models with limited substitution opportunities, little technological learning, and limited flexibility about when and where to cut emissions[3].

The meta-analysis work essentially treats the output of each model as data, and then quantifies the importance of parameters and assumptions common to the various models in generating results. The analysis generates an overarching model, based on estimates of the impacts of individual model characteristics. This can be used to predict costs as a percentage of world GDP in any year, for any given mitigation strategy. Table 10.1 shows estimated costs in 2030 for stabilisation at 450ppm CO_2. This corresponds with approximately 500-550ppm CO_2e, assuming adjustments in the emissions of other gases such that, at stabilisation, 10-20% of total CO_2e will be composed of non-CO_2 gases (see Chapter 8).

A feature of the model is that it can effectively switch on or off the factors identified as being statistically and economically significant in cutting costs. For example, the ‘worst case’ assumption assumes that all the identified cost-cutting factors are switched off – in this case, costs total 3.4% of GDP. At the other extreme, the ‘best case’ projection assumes all the identified cost-cutting factors are active, in which case mitigation yields net benefits to the world economy to the tune of 3.9% of GDP. (Table 10.1 lists the individual estimated contributions to costs from the identified assumptions – a positive percentage point contribution represents the average reduction in costs when the parameter is ‘switched on’).

[2] Terry Barker is the Director of the Cambridge Centre for Climate Change Mitigation Research (4CMR), Department of Land Economy, University of Cambridge, Leader of the Tyndall Centre’s research programme on Integrated Assessment Modelling and Chairman of Cambridge Econometrics. He is a Coordinating Lead Author in the IPCC’s Fourth Assessment Report, due 2007, for the chapter covering mitigation from a cross-sectoral perspective.
[3] Barker et al. (2006) but see also Barker et al. (2004) and Barker (2006)

Table 10.1 Meta-analysis estimates, contributions to cost reduction

Average impact of model assumptions on world GDP in 2030 for stabilisation at 450ppm CO_2 (approximately 500-550ppm CO_2e)
(% point levels difference from base model run)

	Full equation
Worst case assumptions	**-3.4**
Active revenue recycling[4]	1.9
CGE model	1.5
Induced technology	1.3
Non-climate benefit	1.0
International mechanisms	0.7
'Backstop' technology	0.6
Climate benefit	0.2
Total extra assumptions	**7.3**
Best-case assumptions	**3.9**

Source: Barker et al. 2006

It is immediately obvious that no model includes all of these assumptions to the extent suggested here. This is because in practice, not all the cost-cutting factors are likely to apply to the extent indicated here, and the impact of each assumption is likely to be exaggerated (for example the active recycling parameter is based on the data from only one model[2]).

Nevertheless, the exercise suggests that the inclusion in individual models of induced technology, averted non-climate-change damages (such as air pollution) and international emission-trading mechanisms (such as carbon trading and CDM flows), can limit costs substantially.

The time paths of costs also depend crucially on assumptions contained within the modelling exercises. A number of models show costs rising as a proportion of output through to the end of the century, as the rising social cost of carbon requires ever more costly mitigation options to be utilised. Other models show a peak in costs around mid-century, after which point costs fall as a proportion of GDP, reflecting cost reductions resulting from increased innovation (see Section 10.3). In addition, greater disaggregation of regions, sectors and fuel types allow more opportunities for substitution and hence tend to lower the overall costs of GHG mitigation, as does the presence of a 'backstop' technology[5].

10.3 Key assumptions affecting cost estimates

Other model-comparison exercises, including studies broadening the scope to include non-carbon emissions, draw similar conclusions to the Barker study. A number of key factors emerge that have a strong influence in determining cost estimates. These explain not only the different estimates generated by the models, but also some of the uncertainties surrounding potential costs in the real world. These considerations are central, not only to generating realistic and plausible cost estimates, but also to formulating policies that might keep costs

[4] The parameter can be interpreted as switched 'off' for models where no account is taken of revenues (effectively only the changes in relative prices are modelled) and 'on' for models where the revenues are recycled in some way. Unfortunately, the data underpinning this parameter are thin: among the IMCP models, only E3MG models the use of revenues at all.

[5] Under the assumption of a 'backstop' technology, energy becomes elastic in supply and the price of energy is determined independently of the level of demand. Thus, 'backstop' technologies imply lower abatement costs with the introduction of carbon taxes. The 'backstop' price may vary through technical change. For example, wind, solar, tidal and geothermal resources may serve as 'backstop' technologies, whereas nuclear fission is generally not, because of its reliance on a potentially limited supply of uranium. In practice, very few technologies will be entirely elastic in supply: even wind farms may run out of sites, and the best spots for catching and transporting electricity from the sun may be exhausted quickly.

low for any given mitigation scenario. The overarching conclusion of the model studies is that costs can be moderated significantly if many options are pursued in parallel and new technologies are phased in gradually, and if policies designed to induce new technologies start sooner rather than later. The details will be quantified bellow, but the following key features are central to determining cost estimates.

Assumed baseline emissions determine the level of ambition.

The cost of stabilising GHG emissions depends on the amount of additional mitigation required. This is given by the 'mitigation gap' between the emissions goal and the 'business as usual' (BAU) emissions profile projected in the absence of climate-change policies. Scenarios with larger emissions in the BAU scenario will require greater reductions to reach specific targets, and will tend to be more costly. Large differences in baseline scenarios reflect genuine uncertainty about BAU trends, and different projected paths of global economic development.

The 2004 EMF study found a marked divergence in baseline Annex 1 (rich) country emissions projections from around 2040. Rich-country emissions begin at around 26GtCO_2 at the start of the century and then rise to a range of 40-50GtCO_2 by mid-century. By 2100, the range of BAU projections fans out dramatically. Some baseline scenarios show emissions dropping back towards levels at the start of the century while others show emissions rising towards 95 GtCO_2; there is an even spread between these extremes. These different paths encompass a variety of assumptions about energy efficiency, GHG intensity and output growth, as well as about exogenous technological progress and land-use policies.

Technological change will determine costs through time.

Costs vary substantially between studies, depending on the assumed rate of technological learning, the number of learning technologies included in the analysis and the time frame considered[6]. Many of the higher cost estimates tend to originate from models without a detailed specification of alternative technological options. The Barker study found that the inclusion of induced technical change could lower the estimated costs of stabilisation by one or two percentage points of GDP by 2030 (see table 10.1). All the main studies found that the availability of a non-GHG 'backstop' (see above) lowered predicted costs if the option came into play. Chapter 16 shows that climate policies are necessary to provide the incentive for low-GHG technologies. Without a 'loud, legal and long' carbon price signal, in addition to direct support for R&D, the technologies will not emerge with sufficient impact (see Part IV).

How far costs are kept down will depend on the design and application of policy regimes in allowing for 'what', 'where' and 'when' flexibility in seeking low-cost approaches. Action will be required to bring forward low-GHG technologies, while giving the private sector a clear signal of the long-term policy environment (see Part IV).

Abatement costs are lower when there is 'what' flexibility: flexibility over how emission savings are achieved, with a wide choice of sectors and technologies and the inclusion of non-CO_2 emissions.

Flexibility between sectors. It will be cheaper, per tonne of GHG, to cut emissions from some sectors rather than others because there will be a larger selection of better-developed technologies in some. For example, the range of emission-saving technologies in the power generation sector is currently better developed than in the transport sector. However, this does not mean that the sectors with a lack of technology options do nothing in the meantime. Indeed, innovation policies will be crucial in bringing forward clean technologies so that they are ready for introduction in the long term. The potential for cost-effective emission saving is also likely to be less in those sectors in which low-cost mitigation options have already been undertaken. Similarly, flexibility to cut emissions from a range of consumption options and economic sectors is also likely to reduce modelled costs. Models that are restricted to a

[6] Grubb et al. (2006). See also Grubler et al. (1999), Nakićenović (2000), Jaffe et al. (2003) and Köhler (2006)

narrow range of sectors with inelastic demand, for example, parts of the transport sector, will tend to estimate very high costs for a given amount of mitigation (see Section 10.2).

Flexibility between technologies. Using a portfolio of technologies is cheaper because individual technologies are prone to increasing marginal costs of abatement, making it cheaper to switch to an alternative technology or measure to secure further savings. There is also a lot of uncertainty about which technologies will turn out to be cheapest so it is best to keep a range of technology options open. It is impossible to predict accurately which technologies will experience breakthroughs that cause costs to fall and which will not.

Flexibility between gases. Broadening the scope of mitigation in the cost-modelling exercises to include non-CO_2 gases has the potential to lower the costs by opening up additional low-cost abatement opportunities. A model comparison by the Energy Modelling Forum[7] has shown that including non-carbon greenhouse gases (NCGGs) in mitigation analysis can achieve the same climate goal at considerably lower costs than a CO_2-only strategy. The study found that model estimates of costs to attain a given mitigation path fell by about 30–40% relative to a CO_2-only approach, with the largest benefits occurring in the first decades of the scenario period, with abatement costs on the margin falling by as much as 80%. It is notable that the impacts on costs are very substantial in comparison to the much smaller contribution of NCGGs to overall emissions, reflecting the low-cost mitigation options and the increase in flexibility of abatement options from incorporating a multi-gas approach[8] [9].

However, given that climate change is a product of the stock of greenhouse gases in the atmosphere, the lifetime of gases in the atmosphere also has to be taken into account (see Chapter 8). Strategies that focus too much on some of the shorter-lived gases risk locking in to high future stocks of the longer-lived gases, particularly CO_2.

Some countries can cut emissions more cheaply than other countries, so 'where' flexibility is important.

Flexibility over the distribution of emission-saving efforts across the globe will also help to lower abatement costs, because some countries have cheaper abatement options than others[10].

- **The natural resource endowments of some countries will make some forms of emissions abatement cheaper than in other countries**. For example, emission reduction from deforestation will only be possible where there are substantial deforestation emissions. Brazil is well suited to growing sugar, which can be used to produce biofuel cheaply, although, to the extent that biofuels can be transported, other countries are also likely to benefit. Brazil, like many other developing countries, also has a very good wind resource. In addition, the solar resources of developing countries are immense, the incident solar energy per m^2 being 2-2.5 times greater than in most of Europe, and it is better distributed throughout the year (see Chapter 9).

- **Countries that have already largely decarbonised their energy sector are likely to find further savings there expensive.** They will tend to focus on the scope for emissions cuts elsewhere. Energy-efficiency measures are typically among the

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[7] EMF-21; see Weyant et al. (2004), van Vuuren et al. (2006)

[8] The EMF found that as much as half of agriculture, waste and other non-CO_2 emissions could be cut at relatively low cost. The study looked at how the world might meet a stabilisation objective if it selected the least-cost abatement among energy-related CO_2 emissions and non-CO_2 emissions (but not land use). Two stabilisation scenarios were compared (aimed at stabilising emissions to 650ppm CO_2e): one in which only energy-related CO_2 emissions could be cut; and another in which energy-related CO_2 emissions and non-CO_2 gases could be reduced. In the 'energy-related CO_2 emissions only' scenario, CO_2 emissions fall by 75% on baseline levels in 2100. Some non-CO_2 gases also fall as an indirect consequence. In the multi-gas scenario, CO_2 emissions fall by a lesser extent (67% by 2100) and there are significant cuts in the non-CO_2 gases (CH4 falling by 52%, N_2O by 38%, F-gases by 73%). CO_2 remains the major contributor to emission savings, because it represents the biggest share in GHG emissions.

[9] Babiker et al. (2004)

[10] Discussion of which countries should pay for this abatement effort is a separate question. Part IV looks at how policy should be designed to achieve emissions reductions, while Chapter 11 examines the possible impacts on national competitiveness.

cheapest abatement options, and energy efficiency varies hugely by country. For example, unit energy and carbon intensity are particularly low in Switzerland (1.2toe/$GDP and 59tc/$GDP respectively in 2002), reflecting the compositional structure of output and the use of low-carbon energy production. By contrast, Russia and Uzbekistan remain very energy- and carbon-intensive (12.5toe/$GDP and 840tc/$GDP respectively for Uzbekistan in 2002), partly reflecting aging capital stock and price subsidies in the energy market (see, for example, Box 12.3 on gas flaring in Russia).

- **It will also be cheaper to pursue emission cuts in countries that are in the process of making big capital investments.** The timing of emission savings will also differ by country, according to when capital stock is retired and when savings from longer-term investments such as innovation programmes come to fruition. Countries such as India and China are expected to increase their capital infrastructure substantially over coming decades, with China alone accounting for around 15% of total global energy investment. If they use low-emission technologies, emission savings can be 'locked in' for the lifetime of the asset. It is much cheaper to build a new piece of capital equipment using low-emission technology than to retro-fit dirty capital stock.

The Barker study also found that the presence of international mechanisms under the Kyoto Protocol (which include international emissions trading, joint implementation and the Clean Development Mechanism) allow for greater flexibility about where cuts are made across the globe. This has the potential to reduce costs of stabilising atmospheric GHG concentrations at approximately 500-550ppm CO_2e by almost a full percentage point of world GDP[11][12]. Similarly, Babiker et al. (2001) concluded that limits on 'where' flexibility, through the restriction of trading between sectors of the US economy, can substantially increase costs, by up to 80% by 2030.

Changes in consumer and producer behaviour through time are uncertain, so 'when' flexibility is desirable.

The timing of emission cuts can influence total abatement cost and the policy implications. It makes good economic sense to reduce emissions at the time at which it is cheapest to do so. Thus, to the extent that future abatement costs are expected to be lower, the total cost of abatement can be reduced by delaying emission cuts. However, as Chapter 8 set out, limits on the ability to cut emissions rapidly, due to the inertia in the global economy, mean that delays to action can imply very high costs later.

Also, as discussed above, the evolution of energy technologies to date strongly suggests that there is a relationship between policy effort on innovation and technology cost. Early policy action on mitigation can reduce the costs of emission-saving technologies (as discussed in Chapter 15).

Cost-effective planning and substituting activities across time require policy stability, as well as accurate information and well-functioning capital markets. Models that allow for perfect foresight together with endogenous investment possibilities tend to show much reduced costs. Perfect foresight is not an assertion to be taken literally, but it does show the importance of policy being transparent and predictable, so that people can plan ahead efficiently.

[11] Richels et al (1998) found that international co-operation through trade in emission rights is essential to reduce mitigation costs of the Kyoto protocol. The magnitude of the savings would depend on several factors including the number of participating countries and the shape of each country's marginal abatement cost curve. Weyant and Hill (1999) assessed the importance of emissions permits and found that they had the potential to reduce OECD costs by 0.1ppt to 0.9ppt by as early as 2010.
[12] For example, Reilly et al. (2004) compare the effectiveness of two GHG abatement regimes: a global regime of non-CO_2 gas abatement, and a regime that is globally less comprehensive and mimics the present ratification of the Kyoto Protocol. The study found that, by 2100, the abatement programme that is globally comprehensive, but has limited coverage of gases (non-CO_2 only), might be as much as twice as effective at limiting global mean temperature increases and less expensive than the Kyoto framework.

The ambition of policy has an impact on estimates of costs.

A common feature of the model projections was the presence of increasing marginal costs to mitigation. This applies not just to the total mitigation achieved, but also the speed at which it is brought about. This means that each additional unit reduction of GHG becomes more expensive as abatement increases in ambition and also in speed. Chapter 13 discusses findings from model comparisons and shows a non-linear acceleration of costs as more ambitious stabilisation paths are pursued. The relative absence of energy model results for stabilisation concentrations below 500ppm CO_2e is explained by the fact that carbon-energy models found very significant costs associated with moving below 450ppm, as the number of affordable mitigation options was quickly exhausted. Some models were unable to converge on a solution at such low stabilisation levels, reflecting the absence of mitigation options and inflexibilities in the diffusion of 'backstop' technologies.

In general, model comparisons find that the cost of stabilising emissions at 500-550ppm CO_2e would be around a third of doing so at 450-500ppm CO_2e.

The lesson here is to avoid doing too much, too fast, and to pace the flow of mitigation appropriately. For example great uncertainty remains as to the costs of very deep reductions. Digging down to emissions reductions of 60-80% or more relative to baseline will require progress in reducing emissions from industrial processes, aviation, and a number of areas where it is presently hard to envisage cost-effective approaches. Thus a great deal depends on assumptions about technological advance (see Chapters 9, 16 and 24). The IMCP studies of cost impacts to 2050 of aiming for around 500-550ppm CO_2e were below 1% of GDP for all but one model (IMACLIM), but they diverged afterwards. By 2100, some fell while others rose sharply, reflecting the greater uncertainty about the costs of seeking out successive new mitigation sources.

Consequently, the average expected cost is likely to remain around 1% of GDP from mid-century, but the range of uncertainty is likely to grow through time.

Potential co-benefits need to be considered.

The range of possible co-benefits is discussed in detail in Chapter 12. The Barker meta-analysis found that including co-benefits could reduce estimated mitigation costs by 1% of GDP. Such models estimate, for example, the monetary value of improved health due to reduced pollution and the offsetting of allocative efficiency losses through reductions in distortionary taxation. Pearce (1996) highlighted studies from the UK and Norway showing benefits of reduced air pollution that offset the costs of carbon dioxide abatement costs by between 30% and 100%. A more recent review of the literature[13] came to similar conclusions, noting that developing countries would tend to have higher ancillary benefits from GHG mitigation compared with developed countries, since, in general, they currently incur greater costs from air pollution.

Analyses carried out under the Clean Air for Europe programme suggest cost savings as high as 40% of GHG mitigation costs are possible from the co-ordination of climate and air pollution policies[14]. Mitigation through land-use reform has implications for social welfare (including enhanced food security and improved clean-water access), better environmental services (such as higher water quality and better soil retention), and greater economic welfare through the impact on output prices and production[15]. These factors are difficult to measure with accuracy, but are potentially important and are discussed further in Chapter 12.

[13] OECD et al. 2000
[14] Syri et al. 2001
[15] A difficulty in evaluating the exact benefits of climate polices to air pollution is the different spatial and temporal scales of the two issues being considered. GHGs are long-lived and hence global in their impact while air pollutants are shorter-lived and tend to be more regional or local in their impacts.

Box 10.1 The relationship between marginal and average carbon cost estimates

It is important to distinguish marginal from average carbon costs. In general, the marginal cost of carbon mitigation will rise as mitigation becomes more expensive, as low-cost options are exhausted and diminishing returns to scale are encountered. But the impact on overall costs to the economy is measured by the average cost of mitigation, which will be lower than those on the margin.

In some cases, for example, where energy efficiency increases or where induced technology reduces the costs of mitigation, average costs might not rise and could be zero or negative, even where costs on the margin are positive and rising. The correlation from plotting carbon tax against losses in GDP from the IMCP study is only 0.37; a survey for the US Congress by Lasky (2003) showed that a similar low correlation can be seen from model results on the US costs of Kyoto (2003, p.92).

Changes in the marginal carbon cost are related, but do not correspond one-for-one, to the average cost of mitigation. The social cost of carbon will tend to rise as the stock of atmospheric GHGs, and associated damages, rises. The marginal abatement cost will also rise, reflecting this, but average abatement costs may fall (see Chapter 9). This explains why some of the models with a high social cost of carbon, and corresponding high carbon price, show very low average costs. The high carbon price is assumed to be necessary to induce benefits from energy efficiency, technological innovation and other co-benefits such as lower pollution. In some cases, these result in a reduction in average costs that raise GDP above the baseline when a stabilisation goal is imposed. This also explains why the work by Anderson (Chapter 9) shows a falling average cost of carbon through time consistent with rising costs on the margin.

Most models represent incentives to change emissions trajectories in terms of the marginal carbon price required. This not only changes specific investments according to carbon content, but also triggers technical change through the various mechanisms considered in the models, including through various forms of knowledge investment. The IMCP project (Grubb et al. 2006) charts the evolution of carbon prices required to achieve stabilisation and shows that they span a wide range, both in absolute terms and in the time profile. For stabilisation at 450ppm (around 500-550ppm CO_2e), most models show carbon prices start off low and rise to US\$360/tCO_2 +/- 150% by 2030, and are in the range US\$180-900/tCO_2 by 2050, as the social cost of carbon increases and more expensive mitigation options need to be encouraged on the margin in order to meet an abatement goal.

After that, they diverge significantly: some increase sharply as the social cost of carbon continues to rise. Others level off as the carbon stock and corresponding social cost of carbon stabilise and a breadth of mitigation options and technologies serve to meet the stabilisation objective. Rising marginal carbon prices need not mean that GDP impacts grow proportionately, as new technologies and improved energy efficiency will reduce the economy's dependence on carbon, narrowing the economic base subject to the higher carbon taxation.

10.4 Understanding the scale of total global costs

Overall, the model simulations demonstrate that costs depend on the design and application of policy, the degree of global policy flexibility, and, whether or not governments send the right signals to markets and get the most efficient mix of investment. If mitigation policy is timed poorly, or if cheap global mitigation options are overlooked, the costs can be high.

To put these costs into perspective, the estimated effects of even ambitious climate change policies on economic output are estimated to be small – around 1% or less of national and world product, averaged across the next 50 to 100 years – provided policy instruments are applied efficiently and flexibly across a range of options around the globe. This will require early action to retard growth in the stock of GHGs, identify low-cost opportunities and prevent locking-in to high GHG infrastructure. The numbers involved in stabilising emissions are potentially large in absolute terms – maybe hundreds of billions of dollars annually (1% of current world GDP equates to approximately $350-400 billion) – but are small in relation to the level and growth of output.

For example, if mitigation costs 1% of world GDP by 2100, relative to the hypothetical 'no climate change' baseline, this is equivalent to the growth rate of annual GDP over the period dropping from 2.5% to 2.49%. GDP in 2100 would still be approximately 940% higher than today, as opposed to 950% higher if there were no climate-change to tackle. Alternatively, one can think of annual GDP being 1% lower through time, with the same growth rate, after an initial adjustment. The same level of output is reached around four or five months later than would be the case in the absence of mitigation costs[16].

The illustration of costs above assumes no change in the baseline growth rate relative to the various mitigation scenarios, that is, it takes no account of climate-change damages. In practice, by 2100, the impacts of climate change make it likely that the 'business as usual' level of world GDP will be lower than the post-mitigation profile (see Chapters 6 and 13). Hence stabilising at levels around 500-550ppm CO_2e need not cost more than a year's deferral of economic growth over the century with broad-based, sensible and comprehensive policies. Once damages are accounted for, mitigation clearly protects growth, while failing to mitigate does not.

The mitigation costs modelled in this chapter are unlikely to make the same kind of material difference to household lifestyles and global welfare as those which would arise with the probable impact of dangerous climate change, in the absence of mitigation (see section II). The importance of weighing together the costs, benefits and uncertainties through time is emphasised in Chapter 13.

10.5 Conclusion

This chapter draws on a range of model estimates with a variety of assumptions. A detailed analysis of the key drivers of costs suggests the estimated effects of ambitious policies to stabilise atmospheric GHGs on economic output can be kept small, rising to around 1% of national and world product averaged over the next fifty years.

By 2050, models suggest a plausible range of costs from –2% (net gains) to +5% of GDP, with this range growing towards the end of the century, because of the uncertainties about the required amount of mitigation, the pace of technological innovation and the efficiency with which policy is applied across the globe. Critically, these costs rise sharply as mitigation becomes more ambitious or sudden.

Whether or not the costs are actually minimised will depend on the design and application of policy regimes in allowing for 'what, where and when' flexibility, and taking action to bring forward low-GHG technologies while giving the private sector a clear signal of the long-term policy environment.

These costs, however, will not be evenly distributed. Issues around the likely distribution of costs are explored in the next chapter. Possible opportunities and benefits arising from climate-change policy also need to be taken into account in any serious consideration of what the true costs will be, and of the implications of moving at different speeds. These are examined further in Chapter 12.

[16] See, for example, Azar (2002)

References

Volume 2 of Jorgenson's book "Growth" and also Ricci (2003) provide a rigorous and thorough basis for understanding the theoretical framework against which to assess the costs of environmental regulation and GHG mitigation. The special edition of Energy Economics 2004 is also recommended and includes a crystal-clear introduction to modelling issues by John Weyant. The study by Fischer and Morgenstern (2005) also offers a comprehensive introduction to the key modelling issues, explaining divergent modelling results in terms of modelling assumptions, while highlighting the importance of 'what, where when' flexibility. Van Vuuren et al. (2006) are among those who take this a step further by allowing for multi-gas flexibility in modelling scenarios.

Edenhofer et al. (2006) review the results of ten IMCP energy modelling exercises examining the costs associated with different stabilisation paths, the dynamics of carbon prices and the importance of key assumptions, in particular, induced innovation. Barker et al. (2006) use a more a quantitative approach to synthesise the results of different model projections and examine the importance of induced technological innovation. Using a meta-analysis estimation technique, they attempt to quantify how important various modelling assumptions are in determining cost estimates for different mitigation scenarios.

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