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Monetary Carbon Values in Policy Appraisal: An Overview of Current Practice and Key Issues

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MONETARY CARBON VALUES IN POLICY APPRAISAL: AN OVERVIEW OF CURRENT PRACTICE AND KEY ISSUES - ENVIRONMENT WORKING PAPER No. 92

By Stephen Smith (University College London) and Nils Axel Braathen (OECD)

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ABSTRACT

Cost-benefit analyses and other quantitative appraisals are used in many countries to support decision-making in different areas of public policy, including many investment projects in sectors such as transport and energy. These decisions can have significant effects – either negative or positive – on future emissions of carbon dioxide and other greenhouse gases and it is important whether, and how, countries incorporate estimates of the marginal value of changes in carbon dioxide emissions into these analyses.

This paper discusses the range of approaches which can be employed to value changes in carbon emissions in policy appraisals, setting out the key issues in the choice of valuation principles, and presents some case studies and a survey of current practice in OECD countries.

The paper comprises four main sections. First, as background to the discussion of carbon valuation for appraisal purposes, Section 2 of the paper sets out the main issues that would be involved in assessing the social cost of emissions of carbon dioxide – the "social cost of carbon" – defined as the monetised value of the world-wide damage caused by the incremental impact of an additional tonne of carbon dioxide emitted at some particular point in time. Some of these pose formidable obstacles to reliable measurement, and the context of international policy and analysis has tended to move away from using explicit estimates of the social cost of carbon to determine climate change policy. Instead, the work of the Intergovernmental Panel on Climate Change (IPCC) and international discussions on climate policy have converged on a consensus that international policy should focus on measures necessary to limit the rise in global mean temperature, relative to pre-industrialisation levels, to two degrees Celsius, a temperature rise which is judged, on the basis of available scientific evidence, to largely avoid the risk of extreme adverse climate effects.

In this context, the choice of values to be used in project and policy evaluation and appraisal is less straightforward than in the case of most other pollutants and environmental effects. Section 3 of the paper discusses the various approaches to carbon valuation that OECD countries have employed for project and policy appraisal. These include values based on the research literature on the social cost of carbon, estimates of the marginal abatement cost that would be incurred in meeting a country's abatement target for greenhouse gases, and the market value of emissions allowances in a carbon trading scheme.

These different approaches have varying strengths and weaknesses in particular applications, and the different choices made by OECD countries are partly a reflection of the different policy contexts within which they are operating, and the implications of these differences for the appropriate valuation of carbon in project and policy appraisal.

Section 4 provides some case studies of the development of policy towards the use of carbon values in project and policy appraisal in a number of OECD countries, while Section 5 gives an overview of the use of carbon values in OECD countries based on a survey of member states' practice and values.

JEL Codes: Q51 (Valuation of environmental effects), Q54 (Climate, Global Warming), Q58 (Environmental economics: Government policy), H43 (Project evaluation / Social discount rate).

Key words: Climate change policy, social cost of carbon, cost-benefit analysis, policy appraisal.

RÉSUMÉ

Les analyses coûts-avantages et d'autres évaluations quantitatives sont utilisées dans de nombreux pays pour étayer la prise de décisions dans différents domaines d'action publique, par exemple dans nombre de projets d'investissement dans les transports ou l'énergie. Ce sont des décisions qui peuvent avoir une influence notable –défavorable ou favorable – sur les émissions futures de dioxyde de carbone et d'autres gaz à effet de serre, c'est pourquoi il importe de savoir si des pays introduisent dans ces analyses des estimations de la valeur marginale des variations des émissions de dioxyde de carbone et comment ils procèdent à cet effet.

Ce rapport examine les différentes approches possibles pour attacher des valeurs aux variations des émissions de carbone dans le cadre de l'évaluation des politiques, en signalant les grands problèmes que pose le choix des principes d'évaluation, et il présente quelques études de cas ainsi qu'une enquête sur les pratiques actuelles en la matière dans les pays de l'OCDE.

Le rapport se compose de quatre sections principales. Tout d'abord, pour jeter les bases de la réflexion sur l'attribution de valeurs au carbone, la deuxième section décrit les grandes difficultés que soulève l'évaluation du coût des émissions de dioxyde de carbone pour la collectivité – le « coût social du carbone » – mesuré en valeur monétaire des dommages causés dans le monde entier par l'impact marginal d'une tonne supplémentaire de dioxyde de carbone émise à un moment précis dans le temps. Certains de ces problèmes compromettent très gravement la fiabilité de la mesure, c'est pourquoi dans le contexte de l'action internationale et dans les travaux d'analyse, on recourt de moins en moins à des estimations explicites du coût social du carbone pour définir les politiques relatives au changement climatique. En revanche, dans les travaux du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) et les discussions internationales concernant la politique climatique, un consensus se dégage sur la nécessité d'accorder la priorité, dans la politique internationale, aux dispositions à prendre pour limiter à deux degrés Celsius la hausse de la température moyenne mondiale par rapport aux niveaux préindustriels, hausse qui permettrait, d'après les données scientifiques disponibles, d'éviter pour une bonne part le risque de perturbations climatiques extrêmes.

Cela étant, le choix des valeurs à utiliser dans l'évaluation et l'analyse préalable des projets et des politiques est moins simple que dans le cas de la plupart des autres polluants et effets environnementaux. La troisième section du rapport aborde les diverses démarches suivies par les pays de l'OCDE pour attribuer une valeur au carbone dans leurs évaluations de projets et de politiques, notamment en se servant de valeurs fondées sur les travaux publiés à propos du coût social du carbone, d'estimations du coût marginal de la réduction des émissions que supposerait la réalisation d'un objectif national de réduction des émissions de gaz à effet de serre, ou de la valeur marchande des permis d'émission sur un marché du carbone.

Les atouts et faiblesses de ces approches diffèrent selon les applications, et les choix des pays de l'OCDE tiennent compte en partie des divers cadres d'action dans lesquels ils opèrent, ainsi que des conséquences de cette diversité sur la valeur qu'il convient d'attribuer au carbone dans les analyses des projets et des politiques.

La quatrième section présente quelques études de cas portant sur l'élaboration de la politique à l'égard des valeurs du carbone retenues pour évaluer les projets et les politiques dans plusieurs pays de l'OCDE, tandis que la cinquième section donne une vue d’ensemble des valeurs du carbone utilisées dans les pays de l’OCDE, à partir d’une enquête auprès des pays membres sur leurs pratiques en la matière et les valeurs qu’ils emploient.

Codes JEL : Q51 (Évaluation des effets sur l'environnement), Q54 (Climat, Réchauffement planétaire), Q58 (Économie de l’environnement : Politiques publiques), H43 (Évaluation de projets ; taux social d’actualisation).

Mots clés : politique relative au changement climatique, politique climatique, coût social du carbone, analyse coûts-avantages, évaluation des politiques.

FOREWORD

This paper was prepared by Professor Stephen Smith of University College London in co-operation with Nils Axel Braathen of the OECD Secretariat.

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MONETARY CARBON VALUES IN POLICY APPRAISAL: AN OVERVIEW OF CURRENT PRACTICE AND KEY ISSUES

1. Introduction

Many investment projects in sectors such as transport and energy, and many other public policies in these and other sectors, can have large impacts – either negative or positive – on emissions of CO_2 and other greenhouse gases (GHG). It is therefore important whether, and how, countries take these impacts into account in their project and policy assessments, ex ante and ex post – as well as whether and how such impacts appearing in the future are discounted to present-day values.

This paper:

- Draws on a survey of current practice by OECD countries, covering the values countries place on changes in GHG emissions in their public project and policy assessments and the discounting rates they apply;
- Describes the key issues involved in assessing the 'social cost of carbon' – the monetised value of the world-wide damage caused by emitting an additional tonne of carbon dioxide;
- Presents the range of purposes for which OECD countries employ carbon values, and discusses the issues that arise in the different choices of values;
- Indicates policy implications and highlights areas where further research would be needed.

In cost-benefit analyses and other quantitative appraisals of the social benefit of capital projects and policy interventions it is common to value the consequences of changes in polluting emissions by their social cost. With carbon dioxide and other greenhouse gases this raises particularly complex issues. As background to the discussion of carbon valuation for appraisal purposes, Section 2 sets out the main issues that would be involved in assessing the social cost of carbon. Some of these pose formidable obstacles to reliable measurement, and the context of international policy and analysis has tended to move away from using explicit estimates of the social cost of carbon to determine climate change policy. Instead, the work of the Intergovernmental Panel on Climate Change (IPCC) and international discussions on climate policy have converged on a consensus that international policy should focus on measures necessary to limit the rise in global mean temperature, relative to pre-industrialisation levels, to two degrees Celsius, a temperature rise which is judged, on the basis of available scientific evidence, to largely avoid the risk of extreme adverse climate effects. To achieve this, the 2014 IPCC report concluded that global greenhouse gas emissions would need to be reduced by some 40% to 70% by 2050, compared with a year 2010 baseline, and development of policy both internationally and at national level is now focussed on the abatement actions required to meet this two-degree target.

In this context, the choice of values to be used in project and policy evaluation and appraisal is less straightforward than in the case of most other pollutants and environmental effects. Section 3 discusses the range of potential applications for which monetary carbon valuations may be required, and the various approaches to carbon valuation that OECD countries have employed for project and policy appraisal. Different approaches have varying strengths and weaknesses in particular applications, and the different choices made by OECD countries are partly a reflection of the different policy contexts within which they are operating, and the implications of these differences for the appropriate valuation of carbon in project and policy appraisal. Section 4 provides some case studies of the development of policy towards the use of carbon values in project and policy appraisal in a number of OECD countries, while Section 5 gives an overview of the use of carbon values in OECD countries, based on a survey of member states' practice and values. Some policy implications are drawn in Section 6, and some areas for further research identified.

2. The global social value of reductions in greenhouse gas emissions

2.1 The social cost of carbon

The social cost of carbon (SCC) is the value of the world-wide damage caused by emitting one additional tonne of carbon dioxide.[1] The damage caused by an additional tonne of carbon dioxide emissions at any particular point in time will depend on the level of greenhouse gases in the atmosphere, and the economic damage will also be affected by the state of the economy, and by adaptation measures that have been taken. Other things being equal, damage from an additional tonne will be higher, the higher the atmospheric concentration of greenhouse gases to which it is added.[2]

Because the social cost of emitting one additional tonne of carbon dioxide varies depending on the level of greenhouse gases in the atmosphere, the social cost of carbon has to be defined on specific assumptions about the current level and future trajectory of atmospheric greenhouse gas concentrations, against which its effects are to be measured. There are a number of possible different assumptions about the trajectory of greenhouse gas concentrations, against which the social cost of carbon could be assessed:

- "Business-as-usual" emissions, in the absence of any (additional) climate change policy measures;
- A target trajectory, such as the maximum emissions consistent with restricting the rise in global mean temperature to two degrees Celsius, the focus of current international policy discussions;
- A trajectory reflecting the level of greenhouse gas abatement which in theory would be optimal from an economic perspective, at which the global marginal damage cost just equals the global marginal abatement cost; this abatement may or may not coincide with the target above; or
- Any other specified level of emissions.

The assumption made about the baseline trajectory of emissions as the basis for measuring the social cost of carbon affects the interpretation that should be placed on the estimates, and, as discussed later, different assumptions may be appropriate for different purposes.

Also, the assumed baseline against which the impact over time of incremental carbon emissions at any particular date is to be assessed will require a forecast of future socio-economic conditions, and this forecast is likely to have a significant influence on the valuation of damage arising from incremental emissions.

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1. Values for the social cost of carbon can be expressed either per tonne of carbon dioxide (the most common format) or per tonne of carbon. A cost of USD 1 per tonne of carbon dioxide is equivalent to a cost of USD 3.67 per tonne of carbon.

2. Carbon dioxide is the most significant of the greenhouse gases implicated in global climate change, accounting for about two thirds of the total climate impact. The effects of other greenhouse gases such as methane, nitrous oxide and CFCs are often expressed in terms of equivalent quantities of carbon dioxide, although the assessment of CO_2-equivalences is imprecise, especially when assessing long-term effects.

In principle the social cost of carbon should include monetised estimates of the incremental impact of the additional tonne of emissions on all of the various effects of climate change. A comprehensive estimate to the social cost of carbon should include elements such as:

- Damage to infrastructure, property and natural habitats from sea level rise;
- Effects on agricultural productivity, taking account of positive and negative effects on crop yields in different locations, and the responses of farmers to these yield changes;
- Effects on human health;
- Property damage from increased frequency and severity of flooding, wild fires and other events caused by changed climate and weather patterns; and
- The adverse consequences of species extinction and other changes to the value of ecosystem services.

In practice some of these effects are much more difficult to assess and value than others. There are particular difficulties in assigning values to the probability and scale of possible "catastrophic" climate effects, and in valuing the consequences of climate change on the broader ecosystem. These effects are, however, central to the case for climate change policy and to the optimal level and timing of policy intervention.

The rate at which natural processes remove additional carbon dioxide from the atmosphere is very slow indeed. According to the scientific assessment in the 2007 IPCC report, not much more than half of carbon dioxide emitted is removed from the atmosphere over the course of the first 100 years following emission, and about one fifth of carbon dioxide will remain in the atmosphere for "many millennia" (IPCC, 2007, chapter 10, page 824). Some other greenhouse gases, in particular methane, have considerably shorter lifetimes in the atmosphere. An incremental tonne of carbon dioxide emissions in one year will therefore raise the atmospheric concentration of greenhouse gases in many future years, measured against a baseline in which the increment to emissions had not occurred. The economic effects of a one tonne increase in emissions in a single year is thus spread out over many future years, and the social cost of carbon sums all of these effects, expressing them in terms of a net present value.

Since anthropogenic climate change is driven by the global concentration of carbon dioxide and other greenhouse gases, the location of emissions does not affect the value of world-wide damage caused by emissions. Consequently, the social cost of carbon is the same, regardless of where the emissions occur. This of course has the important policy corollary that the global social benefit of a one tonne reduction in carbon dioxide emissions is the same, regardless of where the emission reduction occurs. Different countries and regions will however face very different levels of damage from climate change, and may assess the costs of climate change differently.

On the other hand, carbon dioxide emitted at different dates will most likely incur different levels of damage, for two principal reasons. First, damage is a highly non-linear function of the accumulated stock of GHGs in the atmosphere, meaning that the damage caused by one tonne of emissions will be affected by the size of the existing stock of emissions to which it is added. Second, the measure of damage is an economic valuation, and will thus reflect income levels. Processes of economic development and technological change have led to steady increases in global prosperity over recent decades, and are likely to continue to do so. As real incomes grow, willingness to pay to avoid global climate change damage will be likely to increase. Taking these two effects together, the likelihood is that the SCC will increase over time, meaning that the value of the damage caused by a tonne emitted in the future will be greater than the value of damage caused by a tonne emitted now. For example, the range of social cost of carbon values recommended for use in regulatory appraisal in the United States in the report of the Interagency Working Group on Social Cost of Carbon (2013) all rise significantly over time, so that the social cost of carbon emitted in 2050 is roughly double the social cost of carbon emitted in 2010.

The monetisation of climate change effects has been particularly controversial, because – as with market values for traded goods – it accords greater weight to richer people than the poor, despite the likelihood that the most dramatic adverse consequences of climate change will be felt in some of the poorest parts of the world. Pearce (2003) provides an overview of these issues and a vigorous defence of monetisation, arguing that it is unavoidable. He notes that even if explicit monetisation were to be rejected, public choices to incur abatement costs in order to reduce climate change damage cannot avoid assessing climate change costs in relation to monetary values.

The next sections review three key issues in the measurement of the social cost of carbon:

- The extent of uncertainty
- The use of discounting
- Equity weighting.

2.2 Uncertainty

Few, if any, public policy decisions must be made in a context of such extreme uncertainty as those which turn on the costs and benefits of climate change policy. The recognition of uncertainty is not a matter of scepticism about climate change, but an unavoidable and inherent feature of the policy context. Even among those who are convinced of the scale and significance of global climate change, and of the urgency of action, there is widespread recognition that there can be no certainty about the range of effects that will be encountered, their magnitude or their timing.

This uncertainty includes scientific uncertainty about the natural processes involved, which translate an incremental tonne of emissions into eventual physical consequences, such as sea level rise, changes in crop yields, the geographical spread of tropical diseases, the frequency and severity of extreme weather events and so on. These aspects of non-economic uncertainty include three key steps:

- Uncertainty in the projection of future emissions of greenhouse gases. One key uncertainty, for example, is how rapidly global energy demand will grow, as a result of economic growth, demographic changes and changes in the technologies of energy production and consumption, all of which are difficult to predict over long time periods. In addition, there are uncertainties about the mix of energy sources which will be used – what proportion of the world's energy needs, in the absence of policy, will be met by fossil-fuel sources, and what proportion by renewables and nuclear.
- Uncertainty about the effects of past and future emissions on the climate system. This includes uncertainty about how past and future emissions translate into a stock of greenhouse gases in the atmosphere, and how the stock of greenhouse gases translates into changes in the global climate.
- Uncertainty about the impact of climate changes on the physical and biological environment. How does a particular climate change affect crop yields, sea level rise, flooding patterns, the geographical range of tropical diseases, species extinction, and so on?

These issues have been extensively researched, and while further research may increase understanding of the processes involved, and narrow the range of uncertainty to a certain extent, there will remain a high level of residual uncertainty. The global climate is moving into unexplored territory, and modelling the effects will include some elements which can be little more than – highly sophisticated – educated guesses. Policy decisions will inevitably have to be made against a backdrop of substantial uncertainty.

Assessing the economic consequences of these changes in the climate and the physical and biological environment also involves substantial uncertainty.

- One aspect of this is uncertainty about the economic background against which these changes need to be assessed, which requires forecasting the level and pattern of economic development over a very long time period – the next century and beyond. Looking back over the past century, economic growth and technological change have increased real incomes dramatically and delivered much more widely distributed global prosperity. It is difficult to predict with any confidence how far these trends will continue over the next century, but any assessment of the economic costs of climate change and the benefits of policy intervention will be heavily influenced by the assumptions made about future economic growth. Moreover, socio-economic conditions in future years may themselves be influenced by the effects of climate change on the physical and biological environment; indeed, it is possible that severely adverse effects of global climate change could attenuate the process of income growth and development, although the probability and magnitude of any such effect is highly uncertain.

- A second aspect of uncertainty in estimating the impact of changes in the level of carbon emissions concerns how socio-economic systems would respond to different levels of climate change.

- In estimating the social cost of carbon, there is also uncertainty about how to translate the various consequences of climate change into economic values. In many areas, including the valuation of property damage, effects on agricultural productivity, etc., the methods are straightforward, and increasingly refined. Some valuations, especially the appropriate valuation of effects on health and mortality, are much more controversial, and exhibit a wider range of estimates.

A major area of uncertainty concerns the probability and magnitude of possible catastrophic events arising from climate change processes, such as a possible meltdown of the Greenland ice sheet or the possible reversal of ocean currents which would have dramatic implications for the climate in particular parts of the world. While it is difficult to estimate the economic consequences of such an outcome, it is much more difficult to place a probability on the occurrence of such an event, and hence to assess the weight which it should be given in a calculation of the expected value for the social costs of carbon emissions. Uncertainty about the risk of catastrophic events also raises issues of the "risk premium" that a risk-averse society might be willing to pay to avoid possible extreme outcomes. Weitzman (2009) argues that global climate change policy cannot be based on CBA at all, because potentially disastrous processes have unknown probabilities, and will thus not be captured in estimations of SCC. He calls instead for an approach based on a safe minimum standard.

2.3 Discounting

Many countries use cost-benefit analysis for project and policy appraisal and evaluation, and have agreed procedures which specify the discount rate which should be applied in discounting future costs and benefits to present values.[3] The existing methods have typically been developed for analyses of infrastructure projects and other investments where the benefits can be assessed over a relatively short time

3 . For example, the *Green Book* guidance for cost-benefit analyses in the United Kingdom (HM Treasury, 2003), the benefit-cost analysis (BCA) guidance developed for regulatory analysis in the United States (Office of Management and Budget, Circular A-4), and the Norwegian white paper *NOU 2012:16* (Norwegian Ministry of Finance, 2012). The proposals from the Norwegian white paper have been integrated into in the binding cost-benefit guidelines issued by the Ministry of Finance, cf. *www.regjeringen.no/globalassets/upload/fin/vedlegg/okstyring/rundskriv/faste/r_109_2014.pdf*.

period – for example, over the next 20 to 30 years – although there are cases where benefits are evaluated over longer periods.

However, many of the benefits of climate change policy would be felt over a very much longer time horizon, and the social cost of carbon needs to take account of effects stretching over the lifetime in the atmosphere of a tonne of carbon dioxide emissions, which will include effects a century and more into the future. How far the existing discounting conventions in cost benefit analysis are applicable to the case of climate change has been highly controversial. As Greenstone *et al.* (2013) observe, "the choice of a discount rate to be used over very long periods of time raises highly contested and exceedingly challenging scientific, economic, philosophical and legal issues. As a result, there is no widespread agreement in the literature concerning the discount rates that should be used in an intergenerational context."

Some of the quantitative assessments of the economic effects of climate change and the costs and benefits of climate policy have employed discount rates that are broadly consistent with existing practice in other areas of policy appraisal (e.g. Nordhaus, 2008). On the other hand, others have argued that a lower discount rate is appropriate for assessing the very long-term effects involved in climate change. For example, the 2007 Stern Review on the Economics of Climate Change argued that some of the reasons that individuals, and hence the current generation, might discount future consumption in deciding how to allocate resources between the present and the future do not apply in the case of decisions that cross generations. In particular, one motivation for individuals to discount future costs and benefits, the preference for current over future consumption arising from the recognition that any individual has a non-zero probability of death before future benefits can be enjoyed, is not relevant when considering how to weight the interests of current and future generations.

Given the very long time-scale involved, the choice of discount rates has a dramatic effect on the estimated social cost of carbon. Using a 2% discount rate, EUR 100 of benefits received in 100 years' time would have a present value of EUR 13.80, while using a 5% discount rate, EUR 100 received in 100 years' time would have a present value of just 76 cents.

Some non-economist commentators have argued that it is not legitimate to apply any discounting at all in making policy decisions about climate change. However, in his discussion of the social cost of carbon, Pearce (2003) argues that this view cannot be sustained. The absence of discounting would imply that climate change consequences two or three centuries ahead would be given the same weight as costs and benefits occurring now, with the result that the social cost of carbon would be very high indeed. Pearce points out that such a view would imply that the current generation should be willing to accept substantial sacrifices in living standards in order to finance investments to prevent harm at distant dates in the future, and that there is little evidence in the pattern of observed behaviour and current policy to indicate that this is indeed the case.

Two broad approaches can be taken to selecting an appropriate discount rate for the social cost of carbon:[4]

- ***Social time preference***. Following Ramsey (1928) this builds up the discount rate from components reflecting the various reasons for valuing future costs and benefits less highly than present costs and benefits – pure time preference ("impatience"), and the interaction of growth in

4 . Following Arrow et al. (2014), these are often characterised as "prescriptive" and "descriptive" approaches respectively, although it will be observed that both draw on elements of description of actual behaviour, and the use of either for policy analysis implies normative judgements.

incomes and the declining marginal utility of income.[5] Some of these parameters can be inferred from evidence on individual behaviour, while others have been the subject of intense debate, especially over the appropriate values to employ for the very long-term assessments involved in climate change.

- ***Social opportunity cost of capital***. Here, discounting of the returns to an "investment" in reducing climate change costs is justified in terms of the real market returns to alternative investments, on the basis that resources devoted to climate change abatement have an opportunity cost in the form of these alternative returns. Which market rate of return is the appropriate benchmark to use, and how to take account of the distorting effects of taxation on observed market returns make this approach less straightforward to apply than at first sight it might appear. In addition, as Greenstone et al. (2013) discuss, an important issue will be how the returns to climate change investments correlate with returns to other economic investments, since this may justify discounting climate change benefits at a rate above or below the rate on other investments.

In principle, in the operation of a market economy, there should be a long-term tendency to converge on an equilibrium in which preferences between current and future consumption were equal to the market returns to investment – and hence for the two approaches to discounting to converge on the same numerical value – were it not for the effect of taxes driving a wedge between preferences between present and future consumption, on the one hand, and the rate at which market investments transform current savings into future returns on the other. Greenstone et al. (2013) note that market evidence on returns can suggest discount rates as high as 5% or 6%, while discount rates based on social time preference can be considerably lower, often between 1% and 3%. Given this range of views it would make sense to test the returns to climate change investments against a range of possible discount rates.

A further issue which has been the subject of extensive discussion in recent academic and policy literature[6] is that there will be uncertainty about the discount rate arising from uncertainty about market returns, or about factors such as real income growth that enter into the social time preference calculation. The effect of this uncertainty has been shown to imply that discount rates should decline over time, a consideration which is much more important in valuing climate change effects than in most other areas where cost-benefit analysis is employed.

2.4 Equity

Climate change raises profound issues of equity, both within and between generations. Within generations the equity issues arise principally because the people and regions most vulnerable to the effects of climate change tend mainly to be poor – partly because richer communities are often in a better position to protect themselves from or adapt to the consequences of changes in climate and weather patterns, sea level rise, etc. Equity issues arise between generations in two main ways. First, future generations may be richer or poorer than the current generation. If the processes of economic development and industrialisation experienced over the past century continue future generations would be considerably better-off than the current generation. Second, the process of climate change may itself affect the relationship between the incomes of current and future generations. As a result of climate change, future generations will inherit a climate which has been damaged through the atmospheric accumulation of greenhouse gases, and will have to live with the adverse consequences. This may be seen as a reduced inheritance of environmental "assets" or "capital" than past generations received, which may or may not be offset by a greater inheritance of physical capital and/or technology.

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5 . The interaction between the growth of income and the marginal utility of income can also be interpreted as the interaction between rising income and the collective risk aversion of the population.

6 . Arrow et al. (2014) provide an assessment of this issue and its implications for policy.

Where discounting already includes an element relating to the marginal utility of future higher consumption, the issues relating to intergenerational equity are already to a certain extent addressed in computing the social cost of carbon. The intra-generational issues, however, remain, and some have argued that these require inclusion of explicit equity weighting in valuing the adverse consequences of climate change. Others take the view that this is part of a wider issue of economic equity, and that it is inappropriate to include equity weighting in the calculation of climate change effects, or inappropriate to include an equity weighting that exceeds the willingness of richer communities to redistribute income to poorer communities in other areas of policy.

Equity weighting can make a substantial difference to estimates of the social cost of carbon. In their 2002 review Clarkson and Deyes suggest that as a rule of thumb estimates incorporating equity weighting can be around double the value without equity weighting. However, the size of any difference depends on the weight which should be accorded to equity within the calculation, and this is not a matter on which there is any real consensus.

3. Carbon values in policy appraisal and evaluation

3.1 Potential uses of carbon values

Cost-benefit analysis is a technique for the quantitative appraisal of project and policy options and the ex post evaluation of project and policy outcomes, which aims to evaluate the full range of consequences, both positive and negative, using money values as the basis for measurement. Typically, costs and benefits at different dates are discounted to present value terms. Costs and benefits which take the form of traded goods and services are valued in terms of their opportunity cost – in other words, the money value of the alternative use of the resources (labour, capital, natural resources, etc.) used for their production; in most cases, this will mean that they are valued in terms of their prices, as determined by market forces, with appropriate adjustments for taxation. Costs and benefits which are not normally the subject of market transactions are valued, in principle, in broadly equivalent monetary terms, reflecting their contribution to the welfare of individuals and the output of firms. A range of techniques are available to infer monetary values for such things as changes to individuals' leisure time, health and mortality risks, their enjoyment of environmental amenities and their experiences of environmental harm. If all relevant costs and benefits can be included and assigned monetary values, the decision rule that follows is straightforward: to implement those projects or policies for which the present value of benefits exceeds the present value of costs.[7]

Cost-benefit analyses are widely used to support decision-making in many different areas of government activity in OECD countries, as illustrated by the survey described in Section 5. These include investment projects in the transport sector, especially infrastructure investments such as new roads, bridges, railways and airports, public sector investments in energy production and distribution, assessments of new policy in certain areas, and, in some cases *ex post* assessments of the effectiveness or value-for-money of existing policies. Many of the project and policy decisions where cost-benefit analyses are undertaken as part of the policy assessment and decision process involve effects on emissions of carbon dioxide and other greenhouse gases. This will be particularly true for transport investments and for investments in the energy sector, but project and policy decisions in other areas may well also have some effects on greenhouse gas emissions. In making a full assessment of the consequences of an investment decision, the costs to social welfare of any additional greenhouse gas emissions should be taken into account, and, likewise, any reductions in greenhouse gas emissions achieved as a result of the investment should be valued as a benefit to social welfare.

7 . The decision rule becomes more complicated where the benefits of projects are interdependent, or where projects are mutually exclusive.

This section considers how effects on emissions of carbon dioxide and other greenhouse gases should be valued in cost-benefit analyses and other quantitative policy appraisals, so that the consequences of project and policy decisions for greenhouse gas emissions can be assessed alongside the full range of other relevant costs and benefits.

The estimates of the global social value of reductions in greenhouse gas emissions – the social cost of carbon – discussed in the previous section are a key backdrop to this discussion. Whether it is appropriate, however, to adopt, un-amended, the existing research estimates of the global social cost of carbon for use in national policy appraisals will depend on the context in which countries use cost-benefit analyses, and purpose which cost-benefit analyses are intended to serve.

Estimates of monetary carbon values have a number of different potential applications in policy appraisal and evaluation:

- Project cost-benefit analysis (project appraisal). For example, valuing the changes in carbon emissions from a public transport investment that would reduce private car use.
- Policy impact assessments, as part of cost-benefit analysis, cost-effectiveness analysis or multi-criteria analysis. For example, valuing the carbon emissions reductions as a result of regulations imposing an obligation on power generators to generate a certain proportion of their electricity from renewable energy sources.
- Determining the stringency of policy instruments, such as, for example, the level of emissions standards.
- Determining the efficient rate at which carbon taxes could be set.
- Making decisions about long-term policy goals, such as the adoption of carbon targets for national environmental policy, or national negotiating positions in international climate negotiations.

The context in which these estimates are used can also vary. It could in principle include:

- Decision-making within a government agency or department, whether to undertake a particular project or not, or how to prioritise projects offering the highest social benefit within the constraint of the resources available to the agency.
- Deciding the allocation of resources within government as a whole, to ensure that resources are allocated to the areas offering the highest social benefit. In this context, projects and programmes with environmental benefits may be competing for resources with those offering non-environmental benefits.
- Public education and information about the costs and benefits of government projects and programmes.
- Audit of value for money in public spending, or of the justification of public policies, by audit offices, parliamentary committees, etc. This could potentially include the evidence considered in processes of judicial review and other legal challenges to the decisions made by government agencies.
- External studies, for example commissioned by think-tanks, policy institutes, industrial, social and environmental lobbyists, etc., which seek to advocate particular policy priorities.
- Entirely independent research studies, such as academic research undertaken for public benefit.

Cost-benefit analyses, which potentially may require the inclusion of values for effects from policy-driven changes in carbon emissions, can be employed in all of these contexts, although to widely-varying extent in different countries.

One of the merits of cost-benefit analysis is that it provides a standardised and well-established quantitative methodology that can be employed in public discussion of policy choices and priorities, and which can help narrow down areas of disagreement over policy choices and the use of resources. Governments are not the only "consumers" or "audiences" that are relevant to cost-benefit analysis. Indeed, cost-benefit analysis is potentially as valuable as a tool for accountability when employed in independent audit processes and public debate as it is in contributing to priority-setting within government agencies.

Assessments can be conducted retrospectively, in the form of *ex post* evaluation, as well as prospectively, in the form of cost-benefit analysis to support decisions about the allocation of resources or inform other policy choices. For example, *ex post* analyses might ask whether the resources devoted to a particular project were money well-spent, whether a tax rate on carbon or an emissions trading cap had been set correctly, or whether the right climate change targets had been adopted.

It is clear, therefore, that carbon values may contribute to a wide range of assessments and evaluations, in diverse contexts. The quality of public decision-making and policy debate will be enhanced if the values that are employed in these various applications are based on coherent principles and the best available evidence. Also, while it is important that the values used in project and policy assessments are systematic and evidence-based, the appropriate approach to valuation and the values employed may differ according to the policy context in the country concerned.

3.2 National or global costs and benefits?

One fundamental issue is whether cost-benefit analyses used to support national policy decision-making are intended to reflect only those costs and benefits accruing to residents of the country concerned, or whether account should be taken of the wider – indeed, global – consequences of climate change.

The context of climate change policy differs from the context of many other pollution control measures in that the effects of climate change are driven entirely by *global* emissions, and their accumulation in the atmosphere. For any individual country, the impact of a change in domestic emissions on the global costs of climate change will be small. Few individual countries account for more than 5% of global emissions, meaning that a country acting on its own would only be able to change global emissions by a few percentage points, even with the most drastic abatement action. The national benefit of any carbon abatement will therefore be very small indeed, compared with the world-wide total benefit. In many other areas of policy, costs and benefits accruing outside a country may be a relatively small proportion of the total. In the case of climate change, almost all of the benefits of a country's abatement actions are experienced elsewhere.

Even where the principle is adopted that cost-benefit analyses should be confined to costs and benefits accruing to the country in question, the international dimension of climate change may impact on policy assessment, in two ways.

First, countries are currently engaged in discussions, under the auspices of the United Nations over national commitments to coordinated policy action on climate change. Many OECD countries have in the past taken on quantitative targets to reduce greenhouse gas emissions under the Kyoto protocol, and the current discussions aim to extend national commitments to policy action in three key directions: in terms of the timescale, in terms of the scale of emission reductions, and in terms of the breadth of country participation. Where countries take on commitments to reduce greenhouse gas emissions in the interests of the world community as a whole, cost-benefit analyses which are confined in principle to costs and benefits accruing to the country concerned would nonetheless need to take account of the effects of projects and policies on national greenhouse gas emissions in terms of their contribution to achieving the commitments which the country has made.

Second, the valuation of national costs and benefits from greenhouse gas emissions may need to reflect what other countries do. As noted above, the social cost of carbon – the global social cost of incremental emissions – varies depending on atmospheric concentrations of greenhouse gases, and hence is influenced by changes in emissions by all countries. The benefits of national abatement action will be close-to-zero if no other countries act, since the impact that an individual country's action has on its own experience of climate change will be negligible, and national benefits of greenhouse gas abatement will only be experienced where the national abatement actions are undertaken as part of a commitment by many countries to move together. Direct national benefits from national abatement will still remain negligible – creating, of course, a strong free-riding incentive – but national policy measures could be seen as sustaining the viability of a coordinated programme of policy action taken by many countries, which, in sum total, will significantly reduce the level of emissions and climate damage. Indirectly, then, national abatement could then be seen as generating significant national benefits, as well as direct global benefits.

3.3 The broad approaches available

Among the approaches employed by OECD countries to assess the value of changes in carbon emissions, four different approaches are widely considered and, in some countries, implemented. Changes in greenhouse gas emissions induced by projects or policies can be valued in appraisals by

- estimates of the social cost of carbon;
- estimates of the marginal abatement cost at a target level of emissions;
- the market value of carbon allowances within a carbon trading regime.

These approaches to carbon valuation have strengths and weaknesses. Not all of the approaches would be applicable in any given context. Some are only applicable in particular circumstances, and will be less appropriate in other circumstances. Some of the considerations in the choice of carbon valuations are outlined below, and then illustrated with some case studies of the choices made by a number of individual countries.

3.4 Appraisal values based on estimates of the social cost of carbon

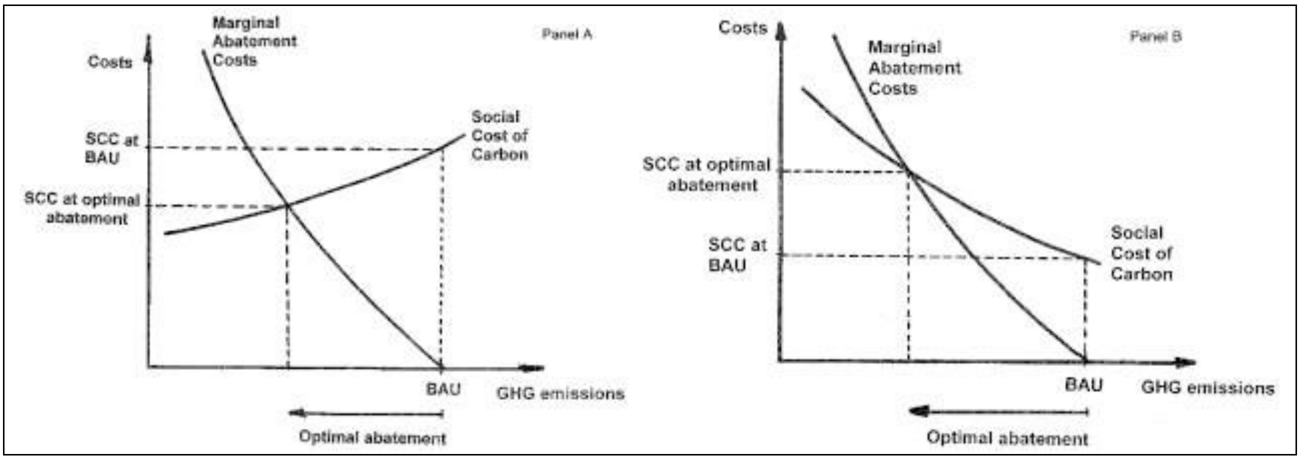
A number of OECD countries value changes in greenhouse gas emissions in project and policy appraisals using estimates of the social cost of carbon. As already noted, the environmental consequences of incremental carbon emissions are likely to vary depending on the stock of carbon dioxide and other greenhouse gases already accumulated in the atmosphere, and the trajectory of further emissions added over the course of their atmospheric "lifetime". A range of different assumptions could be made about this, but the two cases which have been those principally considered are:

- To value incremental carbon emissions or emission reductions which result from a particular project or policy in the country in question on the assumption of "business-as-usual" – in other words, that no additional policies, other than those already in existence, are introduced to curb future global greenhouse gas emissions.

- To value incremental emissions on the assumption that global policies have been adopted to reduce emissions to the level that would be socially optimal from an economic perspective.

The difference in principle between the two valuation approaches can be illustrated by Figure 1. The social cost of carbon can be assessed for an increment to emissions at a particular emissions level, and it will typically vary with the level of emissions and the consequent atmospheric concentration of greenhouse gases. The relationship between the social cost of carbon and the level of emissions traces out the marginal damage cost schedule for the carbon abatement policy decision, and this can then be compared with the marginal abatement cost to determine whether additional abatement generates net costs or benefits. The two schedules show how marginal abatement costs and marginal damage costs vary with the level of emissions, and therefore, over time, with the concentration of greenhouse gases in the atmosphere. The point at which the schedules intersect defines the optimal level of abatement, the point at which the net social benefit of abatement is maximised (Figure 1). At this point, the marginal damage cost of one more tonne of carbon dioxide emitted just equals the marginal abatement cost that would be incurred in its abatement. As Figure 1 shows, the social cost of carbon at the optimal level of abatement differs from the social cost of carbon at the "business-as-usual" level of emissions, reflecting the fact that the damage caused by emissions varies with the atmospheric stock of greenhouse gases.

Figure 1. The social cost of carbon at current and the socially optimal levels of emissions



The two panels of Figure 1 illustrate two different possibilities for the relationship between the social cost of carbon on the optimal abatement path, and the social cost of carbon on a "business as usual" basis. Panel A of Figure 1 illustrates what might be thought of as the "conventional" case, in which the marginal damage cost of carbon emissions declines as emissions are reduced. In this case, the social cost of carbon on the "business-as-usual" basis would be higher than the social cost of carbon with optimal abatement. However, the relationship between the level of emissions and the marginal benefit from carbon abatement – represented by the slope of the marginal damage cost (social cost of carbon) function – may be quite different from the depiction in Panel A of Figure 1. Since the projected rise in temperature is broadly a log-linear function of the atmospheric concentration of greenhouse gases (i.e. concave in concentration) and damages are convex in temperature, it is not clear that marginal damages will be strictly increasing in emissions, and that the marginal benefit of abatement will be decreasing in abatement. If the marginal benefit curve is increasing over a wide enough range of abatement levels, the social cost of carbon along the optimal abatement trajectory can be greater than the social cost of carbon on the business-as-usual emissions path (as illustrated in the Panel B of Figure 1).

The reason that the social cost of carbon at the optimal level of emissions is of interest is that it defines the marginal cost of carbon emissions once global emissions have been reduced to the optimal level (or, more precisely, to a path over time that corresponds to the optimal dynamic trajectory). The social cost of carbon at the optimal level is useful in identifying abatement that makes a cost-effective contribution to that outcome.

The difficulty of applying the social cost of carbon at the optimal emissions level in the context of climate change policy is that it assumes that global policy will be set optimally. Climate change policy involves complex and difficult negotiations, and reaching agreement may require pragmatic compromises that may not always be consistent with optimal abatement or a cost-effective distribution of abatement across countries or regions. The negotiations also are bedevilled by strong incentives for free-riding on the part of individual countries. Assessing the social cost of carbon on the basis of emissions at the point of optimal abatement presumes an outcome that may be difficult to achieve.

In practice, the uncertainties surrounding estimation of the social cost of carbon are – as discussed in Section 2 – very large indeed, and the distinction between estimation on the basis of "business-as-usual" or optimal policy may imply a degree of precision which is unlikely to be attainable.

Some research has suggested that the differences between the social cost of carbon at current (business-as-usual) emissions and the social cost of carbon on the optimal abatement path may in practice be small, over the next few decades at least (Griffiths et al., 2012). However, these results depend on the properties of particular simulation models, and may not hold in other models.

Approaches to carbon valuation based on the social cost of carbon generally take account of world-wide carbon damage, rather than just national carbon damage. Depending on the conventions in policy appraisal and cost-benefit analysis employed in individual countries, this may or may not be consistent with the treatment of other costs and benefits.

The difficulties of reaching a comprehensive and robust estimate of the social cost of carbon are, as discussed in Section 2, substantial, reflecting the large amount of uncertainty involved in climate policy, and the critical importance in valuing future effects of controversial judgements about discounting, equity, and the treatment of risk and uncertainty. Despite these difficulties, a range of research studies provide evidence which can be used to assess the social cost of carbon. As discussed in Section 4, estimates of the social cost of carbon are employed by a number of OECD countries as the basis for carbon valuation in policy appraisal.

3.5 The marginal abatement cost at a target level of emissions

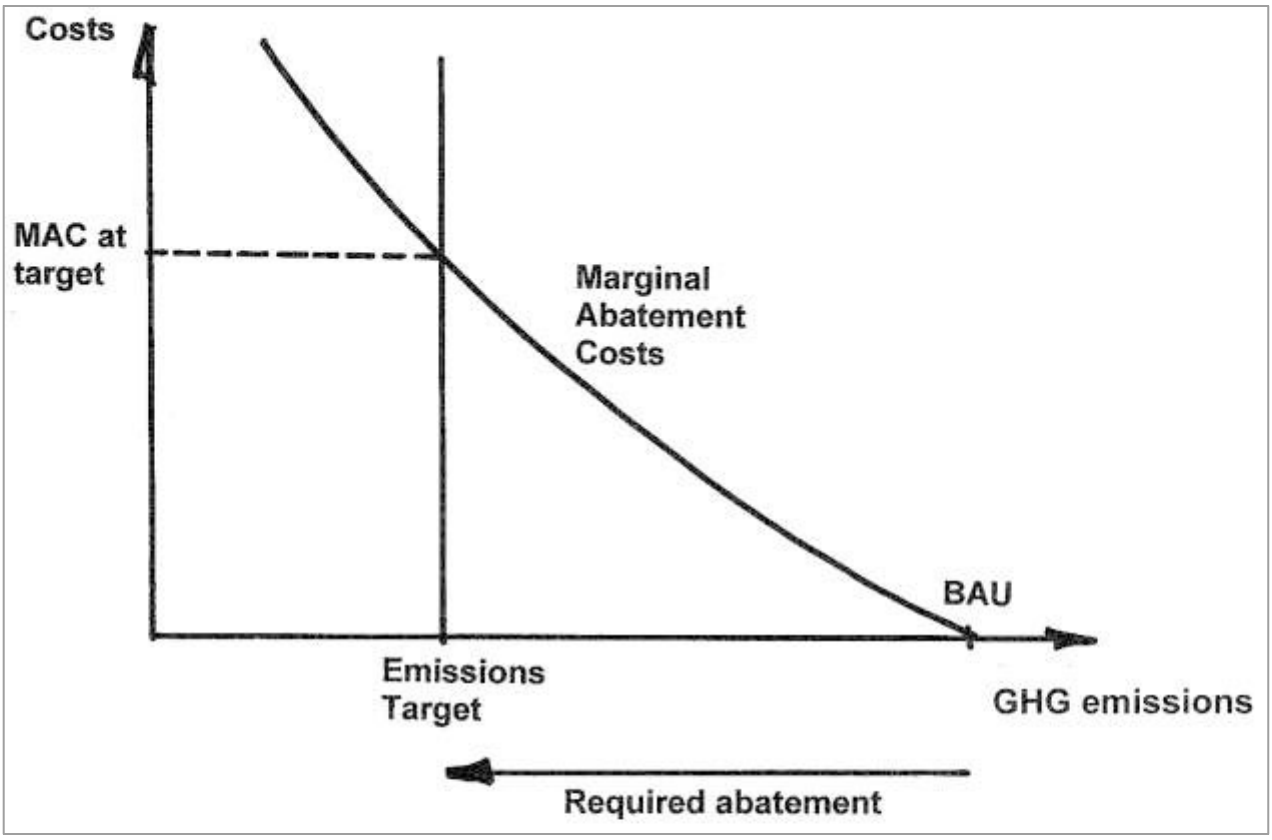
A second broad approach to the valuation of changes in greenhouse gas emissions in project and policy appraisal, which has been employed by a number of OECD countries, is to value emissions changes at the marginal abatement cost for achieving a given target. The target in question could be a purely national target, or it could be a national quantitative commitment to meet a global target in the context of an international agreement (as with the Kyoto Protocol).

Where a country has adopted a particular target for emissions, and is firmly committed to achieving that target, changes in carbon emissions as a result of a project or policy initiative need to be assessed in terms of their impact on the attainment of the overall target. Additional emissions in one area of activity will require a corresponding reduction in emissions to be achieved elsewhere, entailing additional costs of abatement. Conversely, the marginal benefit of carbon abatement as a result of a particular project or policy initiative can be assessed in terms of the cost savings from the alternative abatement that would otherwise have been needed to meet the target. In other words, this approach values marginal emissions of greenhouse gases at the marginal abatement cost at the constraint set by the target, since this defines the opportunity cost of emissions changes, given the requirement that the target must be met. This is illustrated in Figure 2, where the marginal value for carbon abatement is determined by the value of the marginal abatement cost curve at the target level of emissions.

This approach can be seen as a matter of comparing the cost-effectiveness of different projects, within the overall abatement requirement set by the target. The marginal abatement cost at the target distinguishes between projects or other interventions which incur higher costs for carbon abatement and those which are necessary to achieve the target at least economic cost. If a project or programme generates carbon abatement at lower cost per tonne than the marginal abatement cost at the target, social gains can be achieved by displacing the most costly abatement that would otherwise be needed to achieve the target – in other words, the marginal abatement cost at the target.

Where the target is a national target, to be met solely by abatement within the country concerned, the relevant marginal abatement cost for evaluation by an individual country would be based on a marginal abatement cost schedule reflecting costs and opportunities for that particular country, rather than a general or world-wide marginal abatement cost schedule. Where the country has the possibility of meeting its abatement target by purchasing emissions allowances within an international emissions trading system, or by other mechanisms which allow it to receive credit for abatement undertaken abroad, the marginal cost of financing abatement abroad will also need to be taken into account in the abatement cost schedule.

Figure 2. Marginal abatement cost at the target level of emissions



Assessing the social benefit of climate change policy measures with reference to targets that have been set sits uncomfortably with the approach to evaluating other environmental costs and benefits. Similar questions about the value of measures undertaken in the context of an overall target could in principle arise in many other policy contexts, where the targets may be of greater or lesser credibility. The effect of adopting an abatement cost approach to evaluation would be to shift cost-benefit analysis very sharply in the direction of cost-effectiveness and priority-setting, rather than an assessment of overall net social benefits.

Indeed, there is a danger of circularity in judging the consequences of a policy in a cost-benefit analysis by whether the policy contributes to achievement of a selected policy goal. Certainly, a different approach would be required to appraise and evaluate the social benefits of the targets themselves. In effect, a two-stage appraisal and evaluation process is needed, in which the case for the overall targets is evaluated with similar stringency to that which is then applied to project and policy choices within the framework of the specified target.

It has been argued (e.g. DECC, 2010) that a substantial advantage of this approach is that carbon valuations estimated on this basis have a smaller margin of error than carbon values based on estimates of the social cost of carbon. The argument is that while both future abatement costs and marginal damage costs are subject to uncertainty, the level of uncertainty about marginal damage costs is relatively large, and this uncertainty only enters into calculations of the social cost of carbon. Estimating the social cost of carbon on the basis of "business-as-usual" emissions will involve greater uncertainty than estimating carbon value on the basis of marginal abatement cost at the target if uncertainty about marginal damage costs exceeds uncertainty about marginal abatement cost.[8] Estimating the social cost of carbon at the optimal level of abatement requires knowledge of both marginal abatement cost and marginal damage cost, and so will be affected by the uncertainties surrounding *both* functions.

Care needs to be taken in interpreting this argument. Even if it is true that uncertainty about future marginal abatement costs is less than that surrounding marginal damage costs, uncertainty about the social benefits that can be achieved through climate change abatement measures does not disappear as a result of adopting a policy target that can be achieved with relative certainty. The same uncertainties about social benefits remain, but have been partly subsumed in the decision to set a particular target. In fact, the two approaches to carbon valuation attempt to measure different things: one measures the impact of a project or policy in terms of its impact on climate change damage, while the other measures impact in terms of the cost of attaining a chosen target. The second outcome leads to benefits in terms of reduced climate damage only if, and to the extent that, achievement of the target leads to reduced climate damage.

Whether an approach to carbon valuation based on marginal abatement costs is or is not to be preferred to one based on the social cost of carbon depends on the policy context, and on the purpose of the valuation – whether it is to contribute to an assessment of the least-cost way of achieving the chosen target, or whether it is to assess the ultimate social benefit of policies and projects. To the extent that there is an argument for use of values based on marginal abatement costs within a context where there is a firm target commitment, this has nothing to do with the margin of error surrounding the valuation approaches.

A different justification for a focus on target attainment could of course be made in terms of the national benefit of attainment of the target itself. Once a commitment has been made to a particular target, a country may judge that it faces significant reputational, diplomatic or other costs if it fails to achieve the target. This would justify including a measure of target achievement in a cost-benefit analysis, but it does not necessarily imply that these are appropriately valued by marginal abatement cost at the target; the relevant benefits could be higher or lower than this.

8 . While marginal damage costs are, indeed, subject to uncertainty, some of the elements of the marginal abatement cost schedule for future years are heavily influenced by assumptions about technological developments. For example, assumptions about the availability, performance and costs of technologies such as large-scale carbon capture and storage can be very speculative, but could exert substantial influence on future abatement costs, and hence the value to be assigned to changes in carbon emissions many years ahead.

3.6 The market value of carbon allowances within a carbon trading regime[9]

The fourth approach to valuation assesses values for carbon abatement in terms of the price of carbon within an emissions trading scheme. As with the previous approach, this reflects a particular policy context, one in which the emissions concerned fall within the scope of the emissions trading scheme such as the EU ETS.

In assessing the case for this approach to valuation, it is important to be clear about the information that is conveyed by the price of carbon within an emissions trading system. In markets for most goods and services the market price provides information about the marginal cost of production, and the marginal value of consumption. Consumer preferences exercised in a well-functioning competitive market will ensure that additional units will be produced, up to the point where the marginal cost of producing an additional unit equals consumers' willingness-to-pay for the item.

This is not the case for pricing of emissions trading allowances. The value of allowances in the market is determined by the quantity constraint on emissions that is set by the quantity of allowances issued, and its interaction with the marginal abatement costs of firms. Allowance prices are thus dependent on a policy decision, and do not necessarily reveal the strength of public preferences for environmental quality. The only situation in which the carbon allowance price would reflect the social cost of carbon is if the quantity constraint set by the number of allowances issued had happened to coincide with the point where aggregate marginal abatement cost coincided with the social cost of carbon. This will be a matter of luck, or of very precise and well-informed determination of the carbon allowance issue, for which accurate information about the social cost of carbon will have been required. The carbon allowance price in an emissions trading system provides *no independent information* about the social cost of carbon.

Nevertheless, there are circumstances in which it might be appropriate to value carbon emissions in a project or policy appraisal at the market price of carbon within an emissions trading scheme. It could be right to do so when the carbon emissions concerned were included within the scope of the trading system. Then, any additional carbon abatement achieved by the project or policy in question would not lead to any overall change in carbon emissions. It would reduce the number of allowances needed, freeing them up for use elsewhere. Additional abatement through project X then has a social value only to the extent that it reduces the resources that must be devoted to abatement elsewhere, for example in project Y. The benefit of the abatement in X is therefore represented by the marginal reduction in abatement costs elsewhere, which can be measured by the permit value. This will be the case regardless of whether the emissions trading applies domestically or internationally.

For projects and policies affecting carbon emissions in a sector *already* covered by emissions trading it may therefore be appropriate to value the additional carbon emissions reductions at the market allowance price, to reflect the fact that any abatement achieved by project X simply shifts abatement from elsewhere. The market price of emission trading allowances is, however, not an appropriate basis to value any emissions that are outside the scope of the emissions trading regime.

It will be noted that valuing abatement in future periods will require a forecast of future allowance prices. This may be difficult, as allowance prices are dependent on policy decisions about the cap, and hence the scarcity value of allowances. Forecasting variables which are dependent on policy decisions is difficult both in principle and in practice.

9 . This discussion only applies to cap-and-trade or other quantity-constrained trading programmes. In rate-based programmes, such as a tradable performance standard or a clean energy standard, the allowance price is a mix of a compliance price and a subsidy to generation and cannot be interpreted in the way described in this section.

Moreover, in the case of emissions within an emissions trading scheme, it may be appropriate to consider the impact of changes in current emissions on future policy decisions about the continuation of the scheme, and the emissions cap that should be set in future. It is conceivable that the effect of additional abatement achieved now could be to increase the scope for a tighter cap in future, though this raises complex questions of dynamic incentives for abatement behaviour which are difficult to assess.

The case for valuing emissions at the allowance price does not extend to any evaluation of the benefits of the emissions trading system itself. To do so would be circular. An *ex post* evaluation of the impact of the emissions trading scheme should value the abatement achieved using one of the other valuation approaches.

It will be noted that the potential applicability of this approach to valuation is rather wider than it may at first sight appear. Where international agreements provide scope for compliance through purchases of abatement undertaken elsewhere (as with the flexibility mechanisms within the Kyoto Protocol), it is possible that a country's least-cost route to compliance with its international commitments might be by financing abatement elsewhere. The cost of such offset arrangements or certificates might then constitute the marginal abatement cost that the country would face, and hence the appropriate basis for valuing changes in carbon emissions in other areas of policy.

4. Carbon values in selected countries

A number of countries have undertaken exercises to determine carbon values to use in policy appraisal, and three of these are described in this section. These case studies illustrate the different choices taken by countries about the valuation methods discussed in the previous section, and highlight the reasons for the approaches they have adopted.

4.1 Carbon values in the United States

In 2009 the US government convened an interagency working group, comprising scientists and economists from the Environmental Protection Agency (EPA), the Departments of Agriculture, Commerce, Energy and Transportation, the Treasury Department, and the White House to develop an agreed set of estimates of the social cost of carbon that all of the agencies could use in cost-benefit analyses of potential regulatory interventions. Prior to this exercise, a number of agencies had been including assessments of carbon impacts in analyses of proposed policy measures, but on a basis that varied between agencies. The working group aimed to draw on the best available evidence to develop estimates that could be applied systematically and consistently in different areas of policy.[10]

The approach adopted is to assess the global social cost of carbon, in terms of the impact of incremental emissions on global welfare, assessed from the starting point of business-as-usual emissions.

In developing its recommendations, the working group made use of three widely-cited Integrated Assessment Models (IAMs) from the international research literature:

- DICE (Dynamic Integrated Climate Economy), developed by William Nordhaus:

10. The report of the group is Interagency Working Group on Social Cost of Carbon (2010), and the recommended estimates were subsequently updated in 2013 to reflect more recent evidence and model runs (Interagency Working Group on Social Cost of Carbon, 2013). Greenstone, Kopits and Wolverton (2013) describe the working group's methods and the reasoning behind its recommendations. Griffiths et al. (2012) discuss the relevance of its methods and conclusions to policy assessment and evaluation in other countries.

- PAGE (Policy Analysis for the Greenhouse Effect), developed by Chris Hope;
- FUND (Climate Framework for Uncertainty, negotiation and Distribution), developed by Richard Tol.

Each of these models simulate the process by which emissions of greenhouse gases translate into effects in the climate system and the global economy. They are all ‘reduced form models’, which simplify extremely complicated physical and economic processes into a manageable modelling representation, and each makes different judgments about the best way to represent this complex reality. They therefore differ in their underlying structure and representation of climate effects, and also in their scope (for example, FUND does not include estimates of possible ‘catastrophic’ developments at high atmospheric concentrations). As a result, their properties vary significantly, and they generate different projections, even when modelling relatively limited changes in global temperature.

In cost-benefit appraisals of policy interventions with shorter, intra-generational, consequences, US federal agencies employ discount rates of 7% and 3%. The two rates are intended to reflect the different assessments of the discount rate that result from market returns (the “descriptive” approach) and the calculation of the rate of social time preference (the “prescriptive” approach). According the relevant official guidance, the 7% rate is “an estimate of the average before tax rate of return to private capital in the U.S. economy”, while the 3% rate is “the rate at which society discounts future consumption flows to their present value.”[11] Both are designed for costs and benefits that occur in the near to medium term.

For climate change, the interagency working group decided to use three discount rates to cover a ‘plausible range’, a ‘central’ rate of 3% and higher and lower rates of 5% and 2.5% respectively.[12] In making this decision the group noted that the integrated assessment models used to generate the social cost of carbon estimates are designed to estimate change in future consumption-equivalent flows, not capital (or capital equivalent) costs, and so the 3% rate is the appropriate rate to use in this setting. However, the interagency working group decided to also use two additional discount rates to reflect a range of reasonable judgments under both descriptive and prescriptive approaches to discounting. The 5% rate was included to represent the possibility that climate damages are positively correlated with market returns (which would tend to increase the certainty equivalent (consumption) discount rate), and the 2.5% rate reflects the concern that interest rates are highly uncertain over time.

When running the three models, a common set of assumptions was applied for the possible paths of economic and emissions growth and the climate systems responsiveness to increased concentrations of greenhouse gases in the atmosphere – known as equilibrium climate sensitivity. All other features were left at the default values. The model runs produced 45 separate distributions of the social cost of carbon for a given year (3 models x 5 socio-economic scenarios x 1 climate sensitivity distribution x 3 discount rates). The distributions from each model and scenario were equally weighted and combined to produce three separate probability distributions for the social cost of carbon in a given emissions year, one for each of the three discount rates. From the three distributions, four final values were chosen to produce a range that reflects sensitivity to discount rate assumptions and uncertainty in climate sensitivity. The first three values are the average social cost of carbon at each discount rate: 2.5%, 3%, and 5% (Figure 3). A fourth value was chosen to represent the case of higher-than-expected climate change damage; this was based on the 95th percentile of the distribution of values for the 3% discount rate. For emissions in 2020, the recommended values of the social cost of carbon were as follows:[13]

11 . OMB Circular A4.

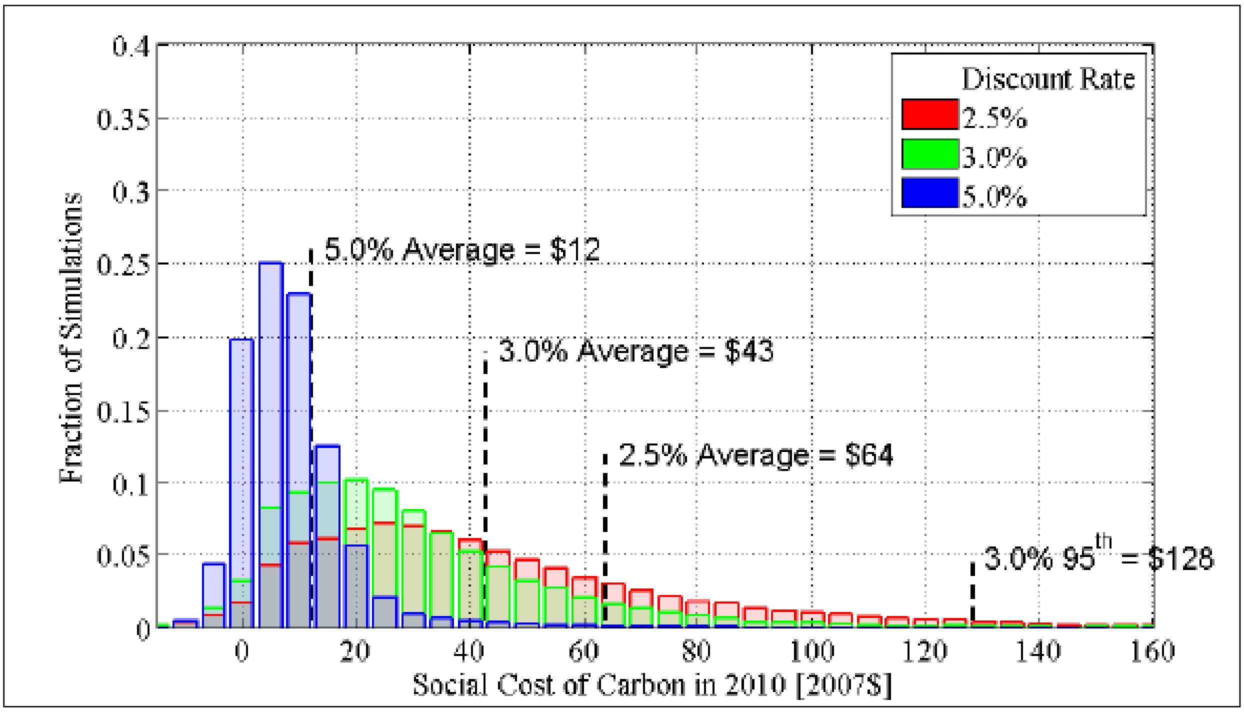
12 . All the rates employed were constant over time.

13 . Updated estimates including November 2013 technical correction (Interagency Working Group on Social Cost of Carbon, 2013).

- USD 64 (2.5% discount rate, average effect);
- USD 43 (3% discount rate, average effect);
- USD 12 (5% discount rate, average effect);
- USD 128 (3 per cent discount rate, 95th percentile of effects).

Figure 3. Distribution of estimates of the social cost of carbon in 2010

2007 USD per tonne of CO2



Note: Updated (2013) estimates including November 2013 technical correction.
Source: Interagency Working Group on Social Cost of Carbon (2013), *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis*.

The working group recognised that the use of such widely-differing estimates of the social cost of carbon would be liable to generate significantly different outcomes from cost-benefit analyses. The group recommended that policy-makers should consider all four estimates, while treating the 3% average value as the central estimate. The intention was that policy-makers should assess the robustness of a proposed policy to a range of conceivable climate values, instead of making assessments on the basis of a single value.

4.2 Carbon values in the United Kingdom

The UK's approach to taking account of the climate change consequences of greenhouse gas emissions in cost-benefit analyses of policy proposals was initially based on work by government economists published as Government Economic Service Working Paper in 2002 (Clarkson and Deyes, 2002). This aimed to estimate the social cost of carbon at the optimal level of abatement. The paper recommended use of a central value for current emissions of GBP 19 per tonne of carbon dioxide, with a range of GBP 10 to GBP 38.[14] Emissions in future years would have higher values, increasing at the rate of GBP 0.27 per tonne of CO_2 per year.

The Stern Review on the Economics of Climate Change, published in 2007, assessed the economic case for climate change intervention. It concluded that the long-run costs of policy inaction would be substantially higher than the likely costs of intervention to stabilise atmospheric concentrations of greenhouse gases. The Review recommended that the optimum climate policy goal for the world should be to aim for stabilisation of atmospheric concentration somewhere in the range 450 to 550 ppm CO_2eq. “Anything higher would substantially increase risks of very harmful impacts but would only reduce the expected costs of mitigation by comparatively little. Anything lower would impose very high adjustment costs in the near term for relatively small gains and might not even be feasible.” (Stern Review, chapter 13). It assessed the social cost of carbon dioxide emissions on an emissions trajectory consistent with stabilising atmospheric concentrations at between 450 and 550 ppm CO_2eq as somewhat higher than the estimates of Clarkson and Deyes, although substantially lower than the social cost of uncontrolled emissions.

Following publication of the Stern Review the UK environment department (Defra) published revised guidance on the valuation of climate impacts in project and policy appraisal (Price, Thornton and Nelson, 2007). Defra took account of the Stern Review’s policy recommendations, and also took on board the new evidence provided by the Stern Review of the social cost of carbon implied by aiming for the proposed stabilisation goal. However, it noted that the proposed values could not be regarded as estimates of the social cost of carbon, noting two areas of difference:

- The stabilisation trajectory for the world as a whole depends on the policy choices taken by all countries, and not just the UK. Assessing the social cost of carbon requires making assumptions about the actions that other countries will take, as well as decisions the UK has made ‘to show leadership in tackling climate change’.
- There is uncertainty about the social cost of carbon associated with the chosen stabilisation goal, and there is no guarantee that policies based on a social cost of carbon believed to be consistent with that goal would actually be sufficient to attain the chosen goal. There was thus a case for adjusting the appraisal values ‘to reflect the marginal abatement cost required to take the world onto the stabilisation goal’.

To signal the shift in focus the Defra 2007 document characterised the recommended appraisal values as the “Shadow Price of Carbon”, for use in policy appraisal, rather than as estimates of the social cost of carbon.

A more fundamental reorientation of UK policy towards appraisal values followed shortly afterwards, as the result of an interdepartmental review of carbon valuation in UK policy appraisal, headed by the department responsible for climate change, DECC. This review (DECC, 2009) recommended that the UK should move towards a ‘target-consistent approach’ to carbon valuation, under which the UK would appraise individual policies that increase or reduce emissions on the basis of a comparison of the costs of abatement under these policies, and the marginal abatement cost that would be incurred in meeting the UK’s chosen target. In sectors outside the EU ETS, this would take the form of the marginal abatement cost that would otherwise have to be incurred in meeting the UK’s target. In sectors covered by the EU ETS, it was recognised that additional abatement by the UK merely increases the scope for additional

14 . Note that Clarkson and Deyes (2002) express the social cost of carbon in terms of a value per tonne of carbon, rather than the current convention, used throughout the present paper, which is to report values per tonne of carbon dioxide. Their recommended central value was reported as GBP 70 per tonne of carbon, which is equivalent to GBP 19 per tonne of CO_2.

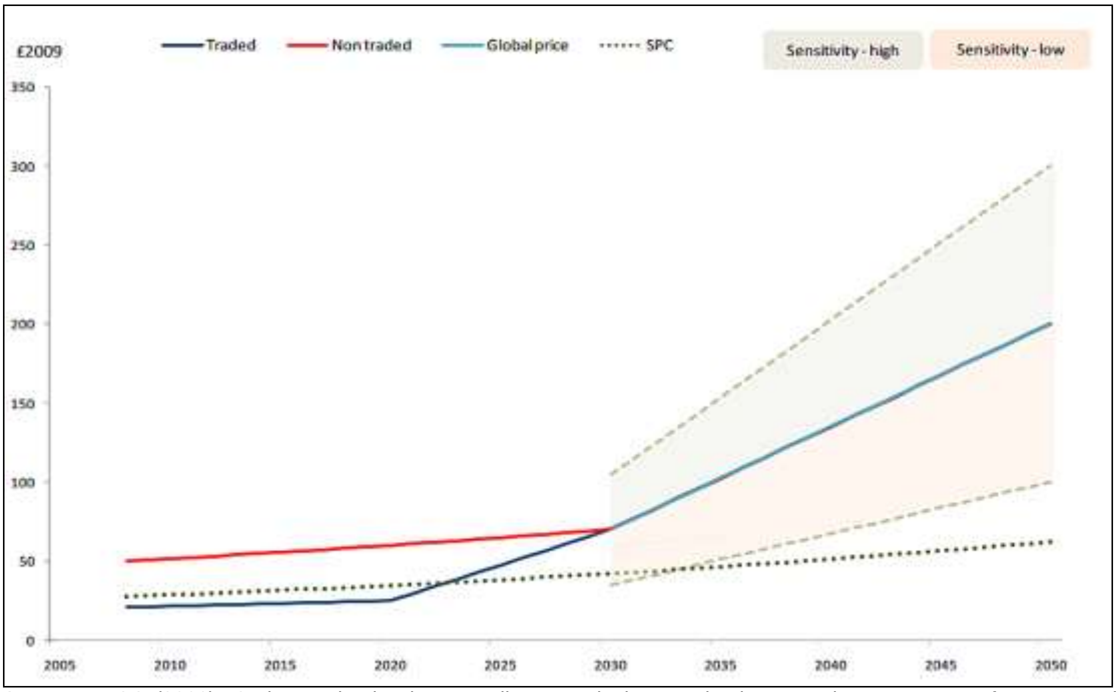
abatement elsewhere in the ETS, so the appropriate valuation for UK abatement in these sectors is simply the cost of the marginal ETS allowance purchases that would otherwise be made.

The 2009 document required these 'target-consistent' values to be used for all appraisals. However, it noted that when the UK considers setting emissions reduction targets for future periods or when policy towards the negotiation of global stabilisation goals is under discussion, use of values derived from current UK targets would be circular and meaningless. In these circumstances, "formal modelling evidence, including the social cost of carbon, will continue to be an important input".

The values specified as a result of this work (Figure 4) are as follows:

Figure 4. UK carbon appraisal values for carbon emissions

In the 'traded' sector (covered by the EU ETS) and the 'non-traded sector' (outside the ETS), compared with the 2007 recommendations for the shadow price of carbon, GBP per tonne of CO2, 2009 prices



Source: DECC (2009). *Carbon Valuation in UK Policy Appraisal: A Revised Approach*, Department of Energy and Climate Change, London.

- A short-term value of carbon to be applied to emissions which are not covered by the EU ETS of GBP 60 per tonne of CO_2, with a range of 50% either side of this central value (i.e. between GBP 30 and GBP 90).
- A long-term value of carbon, to be applied to all emissions, of GBP 70 per tonne of CO_2 in 2030, with a 50% range (i.e. GBP 35 – GBP 105).
- A short-term value of carbon to be applied to emissions in sectors covered by the EU ETS, which was initially set at GBP 25 per tonne of CO_2 in 2020, with a range of GBP 14 – GBP 31. In the light of the continuing weakness of prices within the EU ETS, this has subsequently been updated to a central value of only GBP 5.35 with a range of 0 to GBP 40, rising to a central value by 2030 of GBP 78 (range GBP 39 – GBP 117).
- Values for intermediate years are to be used based on linear interpolation between the values for the benchmark dates.

Subsequently DECC has issued guidance on the valuation of carbon emissions over a longer time horizon, extending from 2050 to the end of the century (DECC, 2011). While recognising that calculating values for this period is subject to much more uncertainty, a linearly increasing schedule of values is proposed for years beyond 2050, with the central carbon value raising to GBP 268 per tonne of CO_2 by 2100, with a range of 75% either side of this value.

4.3 Carbon values in Canada

A paper prepared by Environment Canada (Drzymala et al., 2010) as the basis for interdepartmental discussion has considered how Canada should value the benefits of CO_2 emission reductions within cost-benefit analyses undertaken for Regulatory Impact Analysis Statements (RIAS). The paper reviewed the contrasting approaches of the US and UK in some detail, and concluded that the right approach for Canada to adopt would be to use Social Cost of Carbon values as in the US, but with certain modifications.

Drzymala et al. (2010) argues that a discount rate of 3% should be employed, reflecting the normal recommendation of the Treasury Board Secretariat Cost-benefit Analysis Guide. Two values for the Social Cost of Carbon should be employed, one based on the central value of the US SCC at a 3% discount rate, and the other to allow for the risks of low-probability high-cost "catastrophic" events. This would be based on the 95th percentile estimates from two of the three models used in the development of the US estimates, while dropping the estimates based on the FUND model, which does not model high-cost catastrophic events.

The paper reviewed carefully the arguments for employing the alternative approach, used by the United Kingdom and some other countries, in which carbon values are assessed on the basis of the marginal abatement cost that would be incurred in meeting the country's abatement commitments. The analysis suggested that while there are advantages and disadvantages to both the SCC and MAC in different contexts, the SCC approach is most suitable for the Canadian regulatory context. The authors base this conclusion on the fact that the use of a MAC requires the estimation of the costs associated with attaining a given emissions target, necessitating assumptions regarding federal, provincial and territorial policy choices. The SCC on the other hand, is consistent with other approaches to valuation used in cost-benefit analysis, where values are based on an estimation of marginal damages, and can be integrated in the regulatory framework with ease.

5. Current practice in valuation of changes in GHG emissions

The OECD has carried out a survey about the monetary values of carbon that member countries apply in policy and project assessments, and of the discounting rules they have in place. Twenty three member countries[15] and the European Commission have responded to the questionnaire, fully or partially, which provides a relatively good basis for describing current practices in this area – but the results described below should be interpreted with caution, as the country coverage is not fully complete. There is a possibility that the sample is "biased", in the sense that it is particular countries *not* having clear rules and practices regarding project and policy assessments that have chosen not to respond to the questionnaire.

The information collected represents assessment practices at a national / federal level in the responding countries. In federal countries, the practices will normally vary across different sub-national jurisdictions, but it is not uncommon that they more or less resemble those used at a national level.

15 . Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Israel, Japan, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

Table 1 summarises the questionnaire responses regarding the use of cost-benefit analyses in general, the carbon values used and the use of discounting. It is clear that there are important differences in the elaboration of CBA techniques across different sectors of the economy, and between assessments of public investments and ex ante and (especially) ex post policy assessments in respect to some of the questions. The first question addresses to what extent clear rules have been established for the use of cost-benefit analyses (CBA). Regarding investments in the transport sector, 18 of the 20 countries that have responded to this question indicate that clear criteria are in place for how to carry-out CBAs. For investment projects in other sectors, the share of "yes" responses is somewhat lower, whereas also for ex ante policy assessments, 15 out of 18 responding countries have such rules in place. For ex post assessments, the situation is somewhat different, with only 11 out of 17 responding countries having clear criteria for how to do CBAs.

Turning to what share of cases in the last 3 to 5 years have been the subject of CBAs, the differences are somewhat larger. For transport investment projects, in 90% of the cases,[16] either all or most of the cases had been through a CBA; for ex post policy assessments, this share was only 27%.[17]

When the focus is on whether there are clear criteria for how to include GHG emission changes in the CBAs, the differences between the five categories of assessments studied here are quite large. Such rules are in place for public investment projects in the transport sector in almost two-thirds of the 19 responding countries,[18] but they are absent in 87% of the cases regarding ex post policy assessments.[19] And looking at how often impacts on GHG emissions had been part of CBAs in the last 3 to 5 years, this was the case in all or most cases in 47% of the many countries responding regarding transport sector investments, but only around 20% of the cases in the fewer countries responding to this question regarding ex ante and (especially) ex post policy assessments.

All in all, 50 monetary carbon values have been reported regarding the years 2014, 2020, 2030, 2050 or 2100 in relation to transport sector investments; regarding investments in the energy sector, this number is 32, and for ex ante and ex post policy assessments, the numbers are 23 and 14, respectively. Seventeen countries have provided one or more carbon values being used in one or more assessment types for emissions taking place in the year 2014. For 2030, the number is 16 countries, whereas only two countries have reported carbon values for 2100.

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16 . The question was formulated as follows: "Over the last 3 to 5 years, what is the share of public investment projects in the transport sector for which an ex ante CBA or some other formalised project assessment has been carried out?".

17 . The question was formulated as follows: "Over the last 3 to 5 years, what is the share of major public policies or recent investment projects for which an ex post CBA or some other formalised policy assessment has been carried out?".

18 . The question was formulated as follows: Are there clear criteria indicating when the assessments of transport sector investment projects should include estimated impacts on greenhouse gas (GHG) emissions?".

19 . The question was formulated as follows: Are there clear criteria indicating when ex post assessments of major public policies or investment projects should include estimated impacts on greenhouse gas (GHG) emissions?".

Table 1. Summary of questionnaire responses

		Transport investments		Energy investments		Other investments		New policy assessments		Ex post assessments	
		#	%	#	%	#	%	#	%	#	%
Are there clear criteria for how to do CBAs?	Yes	**18**	90%	**15**	75%	**10**	77%	**15**	83%	**11**	65%
	No	2	10%	5	25%	3	23%	3	17%	6	35%
	Total	20	100%	20	100%	13	100%	18	100%	17	100%
What is the share of cases in the last 3-5 years that have been CB-analysed?	All	3	16%	3	19%	3	25%	4	25%	0	0%
	Most	**14**	74%	**6**	38%	**5**	42%	**8**	50%	4	27%
	Some	1	5%	3	19%	4	33%	3	19%	**6**	40%
	A few	1	5%	3	19%	0	0%	1	6%	2	13%
	None	0	0%	1	6%	0	0%	0	0%	3	20%
	Total	19	100%	16	100%	12	100%	16	100%	15	100%
Are there clear criteria for how to include GHG emission changes in CBAs?	Yes	**12**	63%	6	40%	3	27%	4	24%	2	13%
	No	7	37%	**9**	60%	**8**	73%	**13**	76%	**13**	87%
	Total	19	100%	15	100%	11	100%	17	100%	15	100%
What is the share of cases in the last 3-5 years where impacts on GHG emissions have been part of the CBAs?	All	1	6%	1	7%	1	10%	1	7%	0	0%
	Most	**7**	41%	3	21%	1	10%	2	14%	2	20%
	Some	2	12%	**4**	29%	1	10%	1	7%	0	0%
	A few	3	18%	1	7%	1	10%	3	21%	1	10%
	Not known	2	12%	2	14%	**3**	30%	**5**	36%	3	30%
	None	2	12%	3	21%	**3**	30%	2	14%	**4**	40%
	Total	**17**	**100%**	**14**	**100%**	**10**	**100%**	**14**	**100%**	**10**	**100%**
For how many countries have monetary carbon values been reported?	2014	**13**	26%	**9**	28%	**3**	30%	**7**	30%	**4**	29%
	2020	11	22%	8	25%	**3**	30%	5	22%	3	21%
	2030	**13**	26%	8	25%	2	20%	5	22%	3	21%
	2050	11	22%	6	19%	1	10%	5	22%	3	21%
	2100	2	4%	1	3%	1	10%	1	4%	1	7%
	Total	**50**	**100%**	**32**	**100%**	**10**	**100%**	**23**	**100%**	**14**	**100%**
What is the unweighted average of the values of a tonne of CO_2eq that have been reported – in USD in 2014 money value?	2014	**57**	39%	38	25%	54	26%	56	29%	53	28%
	2020	66	45%	47	30%	69	34%	**82**	43%	68	36%
	2030	99	67%	67	44%	94	45%	**115**	60%	104	55%
	2050	164	112%	153	99%	**348**	169%	237	124%	248	132%
	2100	349	237%	**467**	302%	**467**	226%	**467**	244%	**467**	248%
	Average	**147**	**100%**	**154**	**100%**	**207**	**100%**	**191**	**100%**	**188**	**100%**
What is the standard deviation of the values of a tonne of CO_2eq that have been reported – in USD in 2014 money value?	2014	43	49%	26	44%	37	104%	44	35%	31	49%
	2020	45	51%	26	45%	31	86%	50	39%	32	51%
	2030	59	67%	39	67%	40	110%	62	49%	41	65%
	2050	128	144%	142	243%			147	116%	148	236%
	2100	167	189%					330	261%		
	Average	**89**	**100%**	**58**	**100%**	**36**	**100%**	**127**	**100%**	**63**	**100%**

Table 1. Summary of questionnaire responses

		Transport investments		Energy investments		Other investments		New policy assessments		Ex post assessments	
		#	%	#	%	#	%	#	%	#	%
On which basis were these values established?	Damage costs	**3**	27%	**2**	29%	0	0%	**3**	50%	0	0%
	Required prices	2	18%	**2**	29%	0	0%	1	17%	**1**	50%
	Current policies	**3**	27%	0	0%	0	0%	0	0%	0	0%
	Price projections	1	9%	**2**	29%	0	0%	1	17%	0	0%
	Other	2	18%	1	14%	**1**	100%	1	17%	**1**	50%
	Total	**11**	**100%**	**7**	**100%**	**1**	**100%**	**6**	**100%**	**2**	**100%**

The carbon values used seem at first sight to be relatively similar across the different assessment categories, at least for years up to 2030. When reading the table, it should be kept in mind that the countries included in the averages vary across assessment categories – and that e.g. the average regarding investments in "Other sectors" is based on only three observations. But as can be seen in the tables in the annex, there are large differences in the values used across the countries covered. For example, in relation to transport sector investments, Denmark used a value of USD 19.6 per tonne CO_2eq for emissions occurring in 2014, while Sweden used a value of USD 170.4.

Figures 5 to 8 a give a visual illustration of the distribution of the carbon values over the different years, and by the most relevant assessment categories – except for "other investments".

Figure 5. Monetary carbon values used for investment projects in the transport sector

USD, 2014 money value

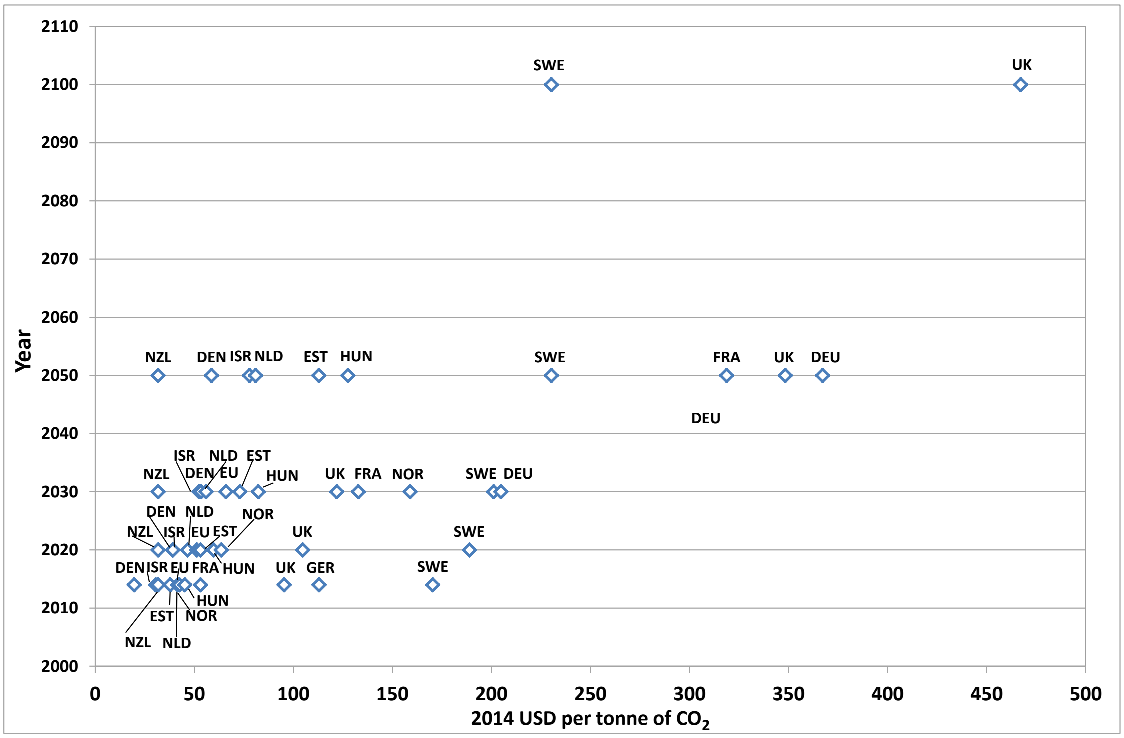


Figure 6. Monetary carbon values used for investment projects in the energy sector
USD, 2014 money value

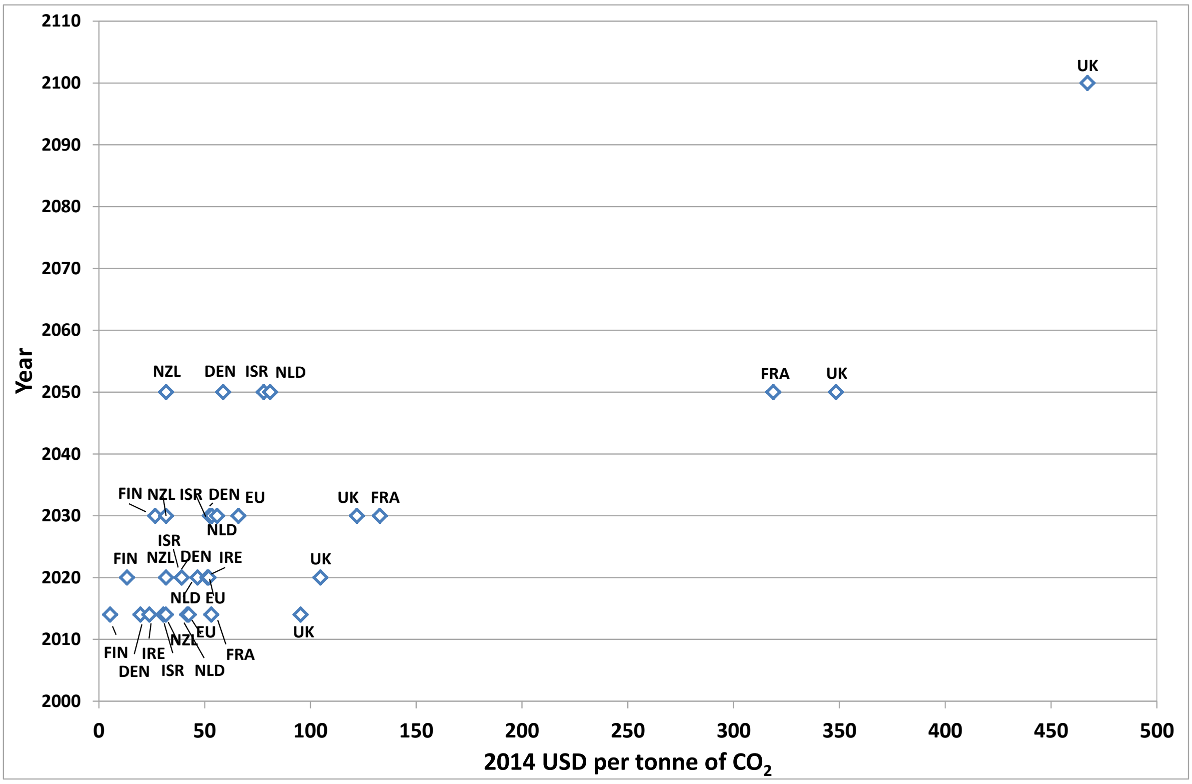


Figure 7. Monetary carbon values used in ex ante policy assessments
USD, 2014 money value

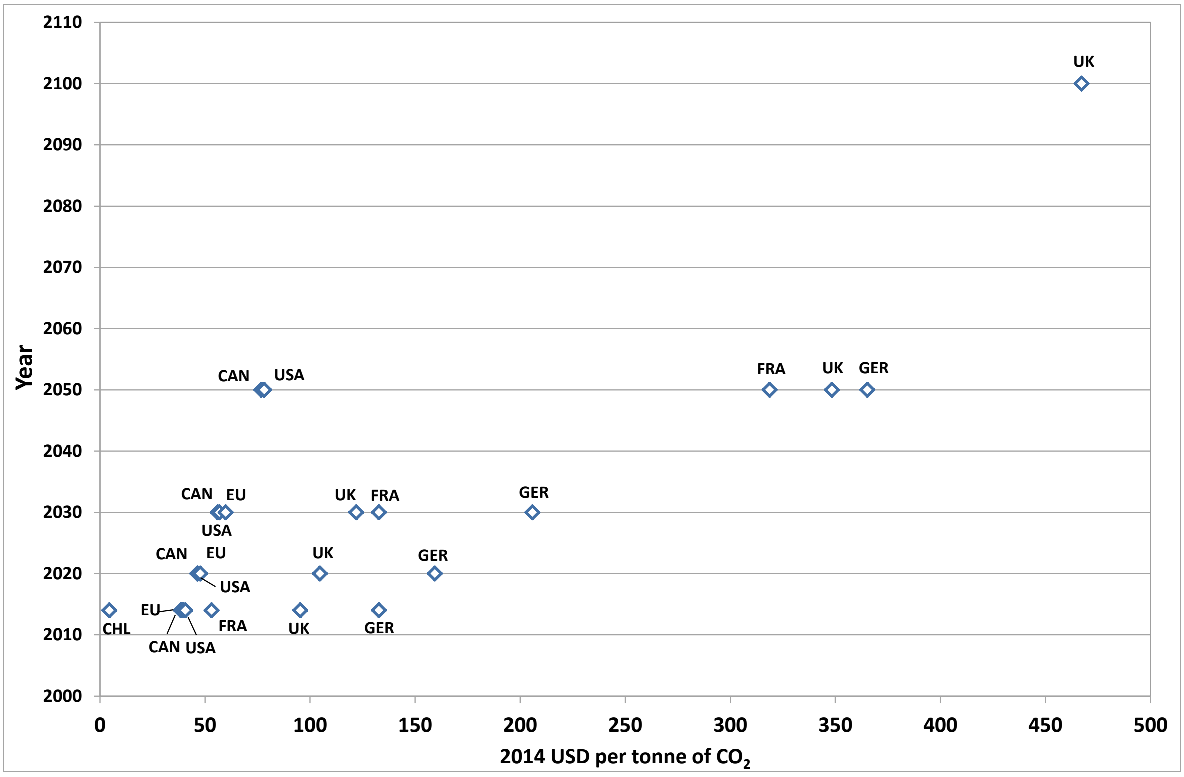
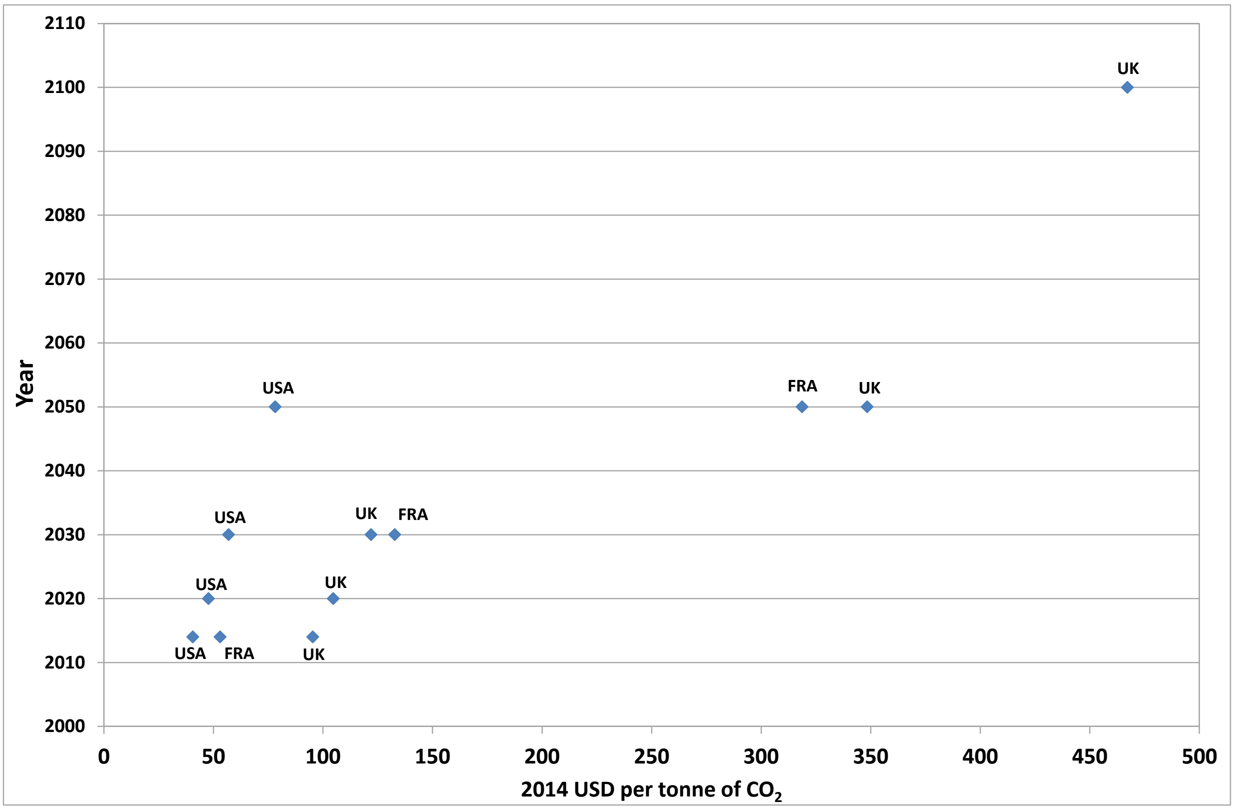


Figure 8. Monetary carbon values used in *ex post* assessments of policies and projects
USD, 2014 money value



Across all the assessment categories, the values used are higher for emissions taking place in future years than for current emissions. For example, regarding transport sector investments, the unweighted average of the values used for emissions taking place in 2014 is USD 57, but for emissions occurring in 2050, the average value used is USD 164 – in 2014 money value. The similar numbers regarding investments in the energy sector are USD 38 and USD 153, and for ex ante assessments of new policies, the values are USD 56 and USD 237, respectively.

There are large variations in the basis on which the carbon values have been selected. For example, regarding investments in the transport sector, three of the 11 responding countries indicate that the values are based on damage cost estimates, and three other countries based their carbon values on some current policy, such as the tax rate for petrol in their carbon tax. Two countries used estimates of the prices necessary to reach a given abatement objective as the basis for their monetary carbon values, and one country based its value on projections of future carbon market prices. The last two countries indicated that the values were based on some other basis. In relation to ex ante assessments of new policies, damage cost estimates was the most common basis for the carbon values used – with 50% of the six responses received.

6. Policy implications and areas for further work

Public agencies make a wide range of decisions with implications for future emissions of carbon dioxide and other greenhouse gases. These include investments in transport infrastructure, investments and regulation in the energy sector, measures to enhance energy efficiency, the specification of building regulations, and waste management policies, as well as broader policy decisions about national climate change policies and the national stance in international negotiations on climate change. In all of these decisions, the consequences of changes in greenhouse gas emissions, in terms of the damage caused by climate change, are a key consideration.

In particular, countries which already use cost-benefit analysis for the appraisal and evaluation of projects and polices need to be able to incorporate estimates of the marginal value of changes in carbon dioxide emissions into these analyses, on a basis consistent with standard cost-benefit procedures.

Cost-benefit analyses potentially play an important role in external audit, assessment and public discussion of climate change policies as well as in decision-making within government agencies. Values for the effects of changes in carbon emissions used in cost-benefit analyses need to be objective and evidence-based, and to be used consistently.

The marginal value of changes in carbon dioxide emissions can be assessed in terms of the "social cost of carbon", which measures the change in world-wide damage caused by emitting one additional tonne of carbon dioxide.

Estimating the social cost of carbon raises difficult issues of discounting, equity and, especially, uncertainty.

- Discounting concerns how we should value costs and benefits in future years in relation to current costs and benefits. While discounting future costs and benefits is common practice both in business decision-making and in cost-benefit analysis, it is a particularly problematic issue in climate change because so many of the consequences of current policy lie so far in the future.
- Equity issues arise, in particular poorer people and countries are the most vulnerable to the adverse effects of climate change.
- Uncertainty lies at the heart of climate change policy. There are major uncertainties concerning many of the key physical and economic processes involved, and these cannot be resolved before major policy choices have to be made.

These three major issues are all key characteristics of the decision-making landscape for climate change policy. Estimates for the social cost of carbon span a wide range, reflecting the nature of the climate change problem. They are heavily influenced by the particular judgements made about discounting, the treatment of equity, and the weight to be given to high-damage scenarios with probably low but also unknown probabilities, which are difficult to model and value.

Estimation of the social cost of carbon, either at current (business-as-usual) emissions, or on a defined abatement trajectory such as the optimal abatement path, balancing abatement costs and benefits, provides carbon values which are consistent with the wider approach to environmental values in cost benefit analysis, and independent of current views about policy. The recent work of the US Interagency Working Group on Social Cost of Carbon provides a thorough assessment of methods for assessing the social costs of carbon, based on up-to-date results from three widely-cited models of climate: economy interactions. It recommends that policy should be assessed on the basis of four possible values for the social cost of carbon, reflecting the genuine and unavoidable uncertainty that surrounds the process and consequences of climate change. The estimates could in principle be adopted by other countries for policy appraisal and evaluation.

Some countries have used other approaches to assess the value of changes in carbon dioxide emissions, reflecting their particular policy context. International discussions on climate change have focused on actions required to limit the rise in global mean temperature to two degrees Celsius, reflecting the consensus of the scientific literature, and many countries have developed national policies which set targets or goals consistent with this objective. For example, the United Kingdom, which has adopted legally binding targets which limit its future carbon emissions, assesses the value of changes in carbon emissions from a particular project or programme on the basis of the marginal cost of carbon emissions abatement at the target that has been set. The logic behind this approach is clear: once a commitment has been made to a specified target, additional emissions in one area of activity require additional abatement elsewhere, and entail the cost of this offsetting abatement. Used systematically in project and policy appraisal, carbon values based on marginal abatement costs can be used to identify the cheapest (most cost-effective) way of achieving the target that has been set. Carbon values derived from this approach for a particular country will generally be specific to that country, since the pattern of marginal abatement costs is likely to differ across countries, and targets too may differ.

It has been suggested that carbon values based on marginal abatement costs have the merit that they can be estimated with less uncertainty than estimates of the social cost of carbon based on information about abatement benefits instead or in addition to abatement costs. However, the two approaches measure different things: one assesses the benefit of changes in carbon emissions in terms of the global social benefit, while the other assesses carbon emissions in terms of their contribution to cost-effective attainment of a target. These approaches are appropriate in different contexts, and to answer different questions, but the relative uncertainty involved in the different estimates is not relevant to the choice between them. Indeed, it is important to recognise that using estimates based on marginal abatement costs does not reduce in any way the amount of uncertainty involved in making climate change policy. Uncertainty is an unavoidable feature of climate change policy, and cannot be avoided by the adoption of a particular appraisal process.

Some countries have used the market price for carbon in emissions trading schemes to value changes in carbon dioxide emissions in cost-benefit analyses and other policy appraisals. This approach is applicable where the changes in emissions associated with a project or programme come within the cap set by an emissions trading system. Then, reductions in emissions from the project concerned would be directly offset by increases in emissions elsewhere, since overall emissions are determined by the cap that has been set. In these circumstances the benefit of a reduction in carbon emissions as a result of the project being assessed will be the marginal abatement costs avoided by correspondingly lower abatement elsewhere within the system, for which the emissions trading price should be an appropriate estimate. However, emissions trading prices would not normally be an appropriate basis to value changes in carbon emissions outside the scope of the trading system; for these emissions one of the other valuation approaches would be needed.

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ANNEX

The tables and graphs below present the central carbon values used in individual countries in the different assessment categories. All the values are expressed in USD in 2014 money value. Where countries had provided numbers based on the money value of some other year, those values have been inflated to 2014 values by the use of the GDP deflators that can be seen in Table A.6.

Table A.1 Carbon values used in CBAs of investment projects in the transport sector
2014 USD values

	2014 value	2020 value	2030 value	2050 value	2100 value
Denmark	19.6	39.2	53.4	58.7	
Estonia	37.8	53.1	73.0	112.9	
France	53.1		132.8	318.7	
Germany	113.0		204.8	367.2	
Hungary	45.2	59.8	82.3	127.5	
Ireland	23.8	51.8	51.8	51.8	
Israel	30.5	39.1	52.4	77.9	
Netherlands	41.7	46.6	55.9	80.9	
New Zealand	31.7	31.7	31.7	31.7	
Norway	41.7	63.6	158.9		
Sweden	170.4	188.9	201.1	230.3	230.3
United Kingdom	95.3	104.7	121.9	348.4	467.2
EU Commission	42.5	51.3	66.0		

Figure A.1 Carbon values used in CBAs of investment projects in the transport sector
2014 USD values

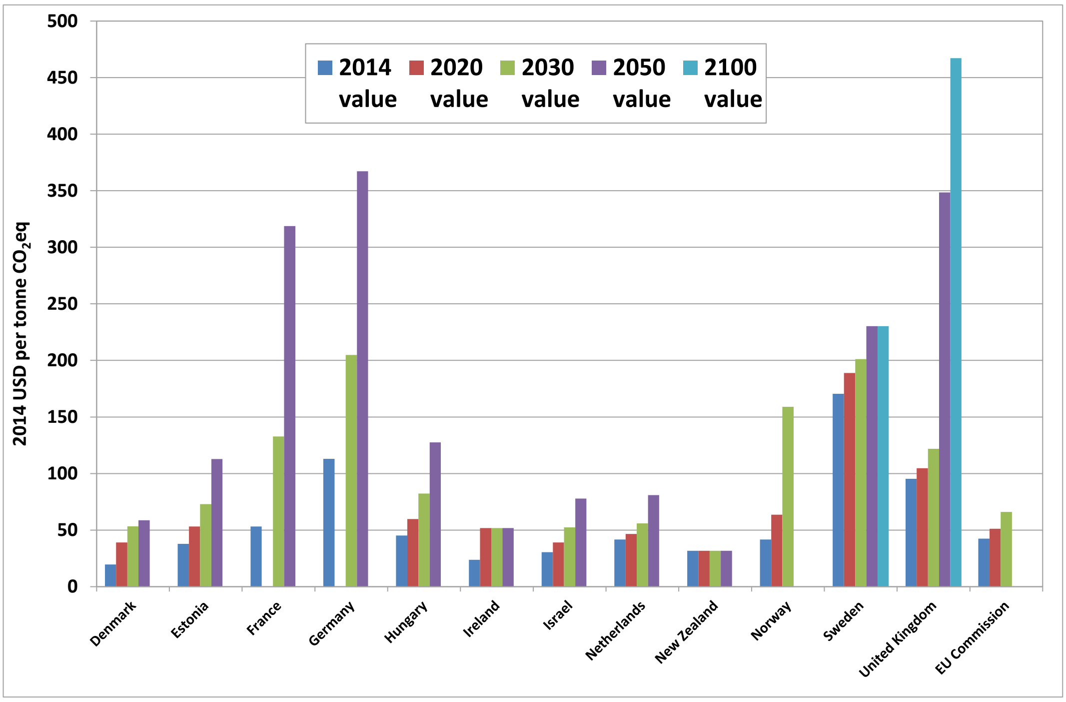

Table A.2 Carbon values used in CBAs of investment projects in the energy sector

2014 USD values

	2014 value	2020 value	2030 value	2050 value	2100 value
Denmark	19.6	39.2	53.4	58.7	
Finland	5.3	13.3	26.6		
France	53.1		132.8	318.7	
Ireland	23.8	51.8			
Israel	30.5	39.1	52.4	77.9	
Netherlands	41.7	46.6	55.9	80.9	
New Zealand	31.7	31.7	31.7	31.7	
United Kingdom	95.3	104.7	121.9	348.4	467.2
EU Commission	42.5	51.3	66.0		

Figure A.2 Carbon values used in CBAs of investment projects in the energy sector

2014 USD values

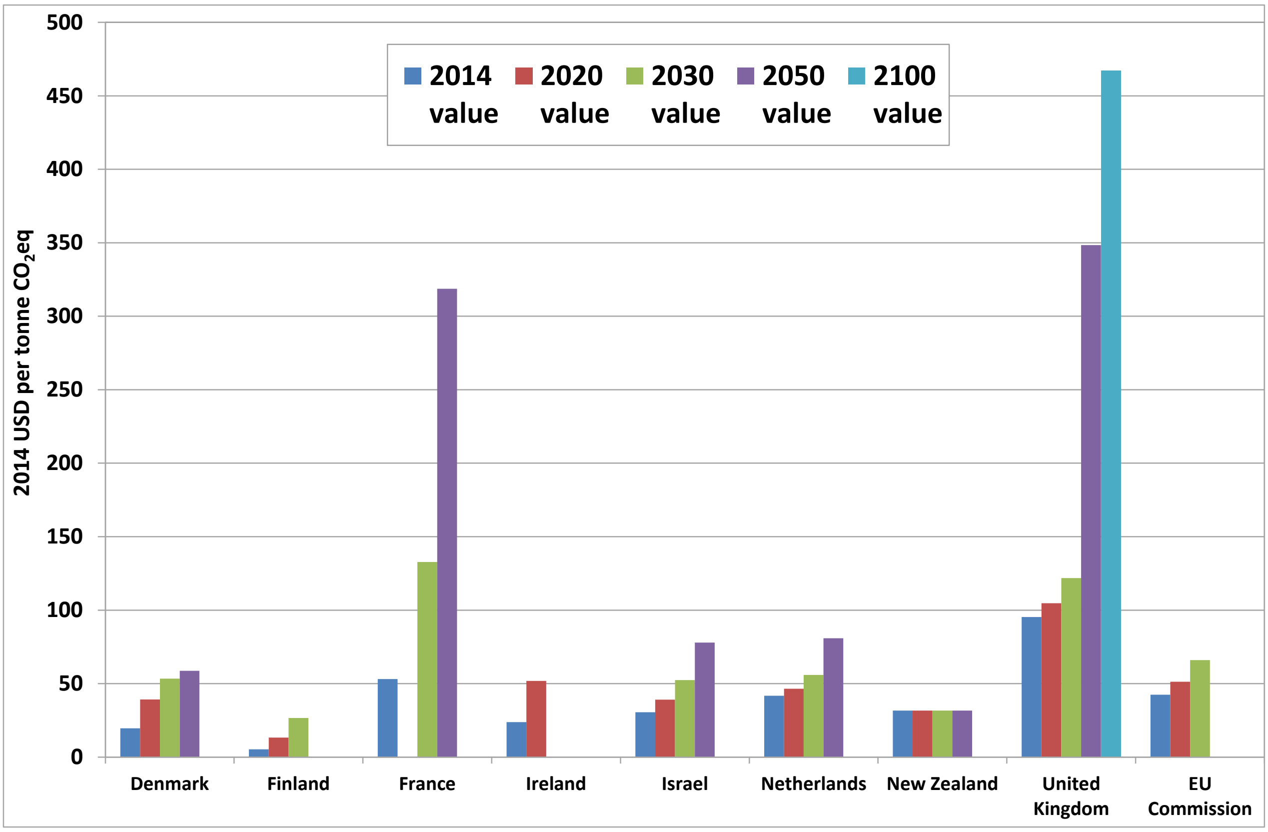

Table A.3 Carbon values used in CBAs of investment projects in other sectors

2014 USD values

	2014 value	2020 value	2030 value	2050 value	2100 value
Ireland	23.8	51.8			
United Kingdom	95.3	104.7	121.9	348.4	467.2
EU Commission	38.5	46.5	59.8		

Figure A.3 Carbon values used in CBAs of investment projects in other sectors

2014 USD values

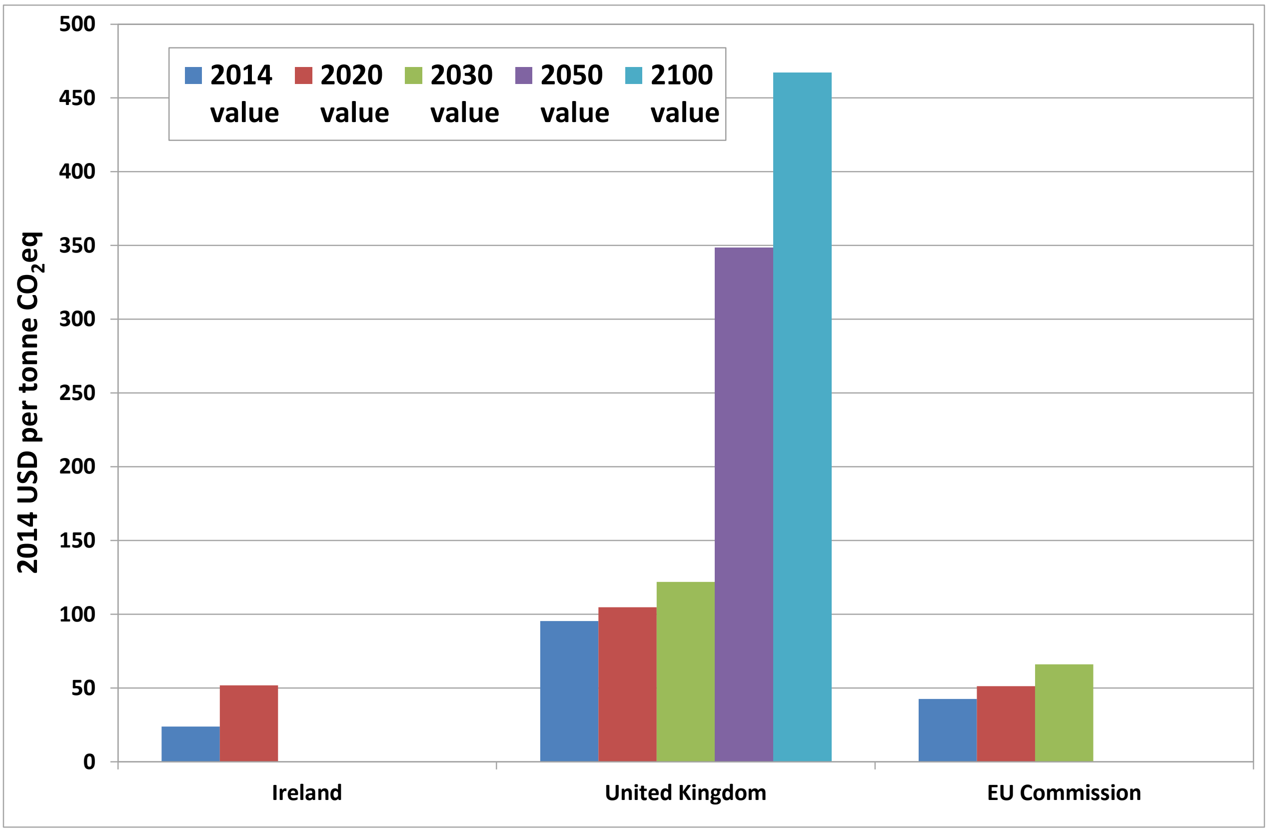

Table A.4 Carbon values used in *ex ante* CBAs of public policies

2014 USD values

	2014 value	2020 value	2030 value	2050 value	2100 value
Canada	39.4	46.3	56.0	76.8	
Chile	4.5				
France	53.1		132.8	318.7	
Germany	132.8	159.4	205.8	365.2	
Ireland	23.8	51.8			
United Kingdom	95.3	104.7	121.9	348.4	467.2
United States	40.6	47.7	56.9	78.2	

Figure A.4 Carbon values used in *ex ante* CBAs of public policies

2014 USD values

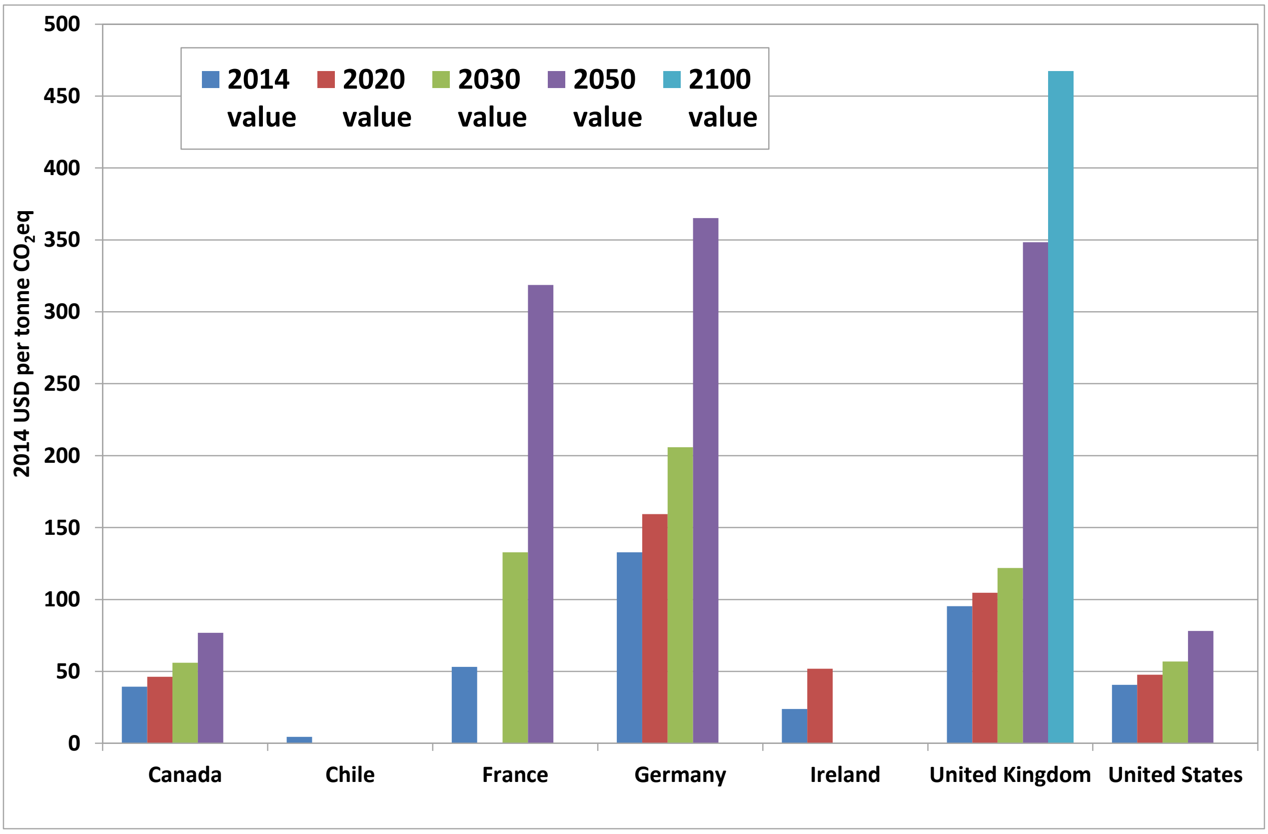

Table A.5 Carbon values used in *ex post* CBAs of public policies or projects

2014 USD values

	2014 value	2020 value	2030 value	2050 value	2100 value
France	53.1		132.8	318.7	
Ireland	23.8	51.8			
United Kingdom	95.3	104.7	121.9	348.4	467.2
United States	40.6	47.7	56.9	78.2	

Figure A.5 Carbon values used in *ex post* CBAs of public policies and projects

2014 USD values

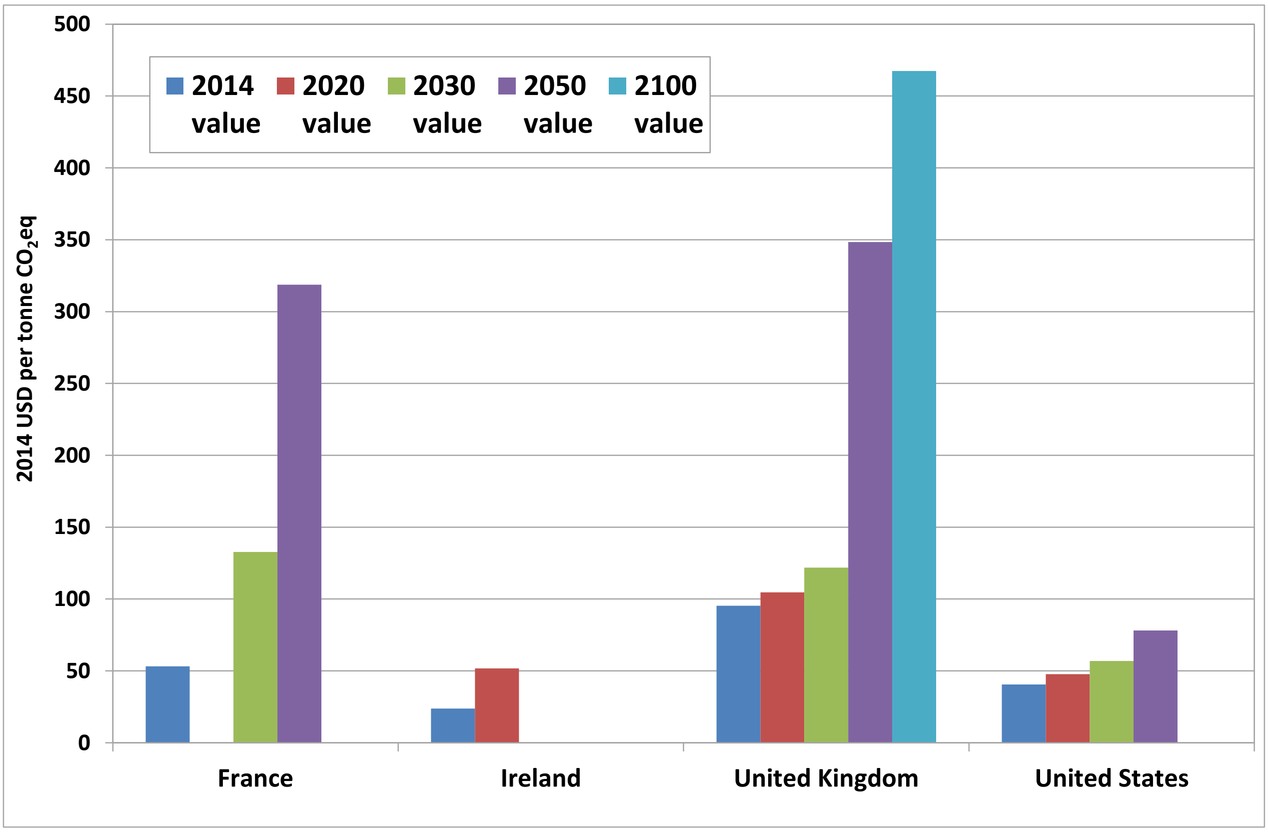

Table A.6 GDP deflators

Market prices, 2010 basis

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Australia	0.810	0.852	0.888	0.945	0.946	1.000	1.042	1.040	1.051	1.068
Austria	0.918	0.935	0.954	0.971	0.983	1.000	1.020	1.038	1.054	1.066
Belgium	0.905	0.926	0.948	0.968	0.980	1.000	1.020	1.040	1.052	1.063
Canada	0.904	0.928	0.958	0.996	0.974	1.000	1.032	1.050	1.063	1.079
Chile	0.746	0.840	0.880	0.885	0.918	1.000	1.034	1.047	1.064	1.115
Czech Republic	0.938	0.943	0.975	0.993	1.016	1.000	0.991	1.007	1.026	1.042
Denmark	0.875	0.894	0.914	0.953	0.959	1.000	1.007	1.030	1.044	1.056
Estonia	0.778	0.846	0.944	0.995	0.997	1.000	1.030	1.064	1.117	1.140
Finland	0.919	0.926	0.954	0.982	0.997	1.000	1.027	1.057	1.078	1.093
France	0.915	0.935	0.959	0.983	0.990	1.000	1.013	1.028	1.040	1.049
Germany	0.952	0.955	0.971	0.978	0.990	1.000	1.012	1.027	1.050	1.063
Greece	0.872	0.893	0.923	0.967	0.989	1.000	1.010	1.007	0.986	0.973
Hungary	0.819	0.851	0.897	0.941	0.977	1.000	1.026	1.057	1.089	1.114
Iceland	0.672	0.731	0.772	0.864	0.935	1.000	1.033	1.062	1.081	1.112
Ireland	1.034	1.068	1.087	1.056	1.015	1.000	1.007	1.013	1.017	1.021
Israel	0.911	0.928	0.927	0.940	0.985	1.000	1.020	1.062	1.088	1.107
Italy	0.914	0.930	0.952	0.976	0.996	1.000	1.014	1.030	1.044	1.048
Japan	1.062	1.050	1.040	1.027	1.022	1.000	0.981	0.973	0.967	0.980
Korea	0.889	0.888	0.909	0.936	0.969	1.000	1.016	1.026	1.034	1.041
Luxembourg	0.832	0.889	0.922	0.926	0.933	1.000	1.042	1.073	1.114	1.121
Mexico	0.782	0.831	0.872	0.926	0.957	1.000	1.052	1.089	1.108	1.150
Netherlands	0.936	0.953	0.970	0.991	0.992	1.000	1.011	1.025	1.039	1.039
New Zealand	0.870	0.892	0.931	0.965	0.972	1.000	1.030	1.024	1.051	1.089
Norway	0.800	0.870	0.897	0.994	0.941	1.000	1.067	1.096	1.125	1.152
Poland	0.874	0.887	0.922	0.951	0.986	1.000	1.032	1.057	1.065	1.071
Portugal	0.917	0.943	0.969	0.985	0.994	1.000	1.003	1.000	1.017	1.018
Slovak Republic	0.941	0.968	0.979	1.007	0.995	1.000	1.016	1.029	1.034	1.042
Slovenia	0.883	0.902	0.939	0.978	1.011	1.000	1.012	1.014	1.024	1.030
Spain	0.907	0.944	0.975	0.998	0.999	1.000	1.000	1.000	1.006	1.008
Sweden	0.899	0.916	0.941	0.971	0.991	1.000	1.013	1.022	1.031	1.042
Switzerland	0.930	0.950	0.974	1.001	0.997	1.000	1.004	1.005	1.004	1.009
Turkey	0.691	0.755	0.802	0.899	0.946	1.000	1.086	1.161	1.229	1.334
United Kingdom	0.874	0.899	0.919	0.949	0.970	1.000	1.023	1.035	1.054	1.070
United States	0.909	0.937	0.962	0.980	0.988	1.000	1.020	1.037	1.053	1.069

Table A.7 Exchange rates

Units of national currency per USD, 2013

Australia	1.036
Canada	1.030
Chile	495.3
Czech Republic	19.560
Denmark	5.618
Hungary	223.6
Iceland	122.2
Israel	3.609
Japan	97.60
Korea	1094.9
Mexico	12.770
New Zealand	1.220
Norway	5.877
Poland	3.160
Sweden	6.513
Switzerland	0.927
Turkey	1.905
United Kingdom	0.640
Euro area	0.753