The Social Cost of Carbon and the Shadow Price of Carbon: what they are, and how to use them in economic appraisal in the UK

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THE SOCIAL COST OF CARBON AND THE SHADOW PRICE OF CARBON: WHAT THEY ARE, AND HOW TO USE THEM IN ECONOMIC APPRAISAL IN THE UK

Richard Price, Simeon Thornton and Stephen Nelson[1]

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This note sets out:

- a definition of the social cost of carbon, hitherto used in UK government appraisals to reflect the external costs of greenhouse gas emissions;

- the rationale for adopting a shadow price of carbon (SPC) for use in policy and investment appraisals across UK government; and the factors which the SPC reflects which the social cost of carbon (SCC) does not;

- our approach to setting the appropriate level for the shadow price of carbon (SPC), now and in the future; and

- how the SPC should be used in policy advice, and why it differs from other carbon price and cost concepts.

Our conclusion is that we should adopt as our starting point an SPC based on an SCC consistent with range of atmospheric concentrations of carbon identified by the Stern Review as the target for global action. Consideration will also be given to adjusting the SPC in the future in order to bring it progressively in line with the level of marginal abatement costs (MAC) consistent with our abatement goal. It will become possible to do this as our knowledge of UK and global MACs improves over the next couple of years.

What is the social cost of carbon?

The social cost of carbon (SCC) measures the full global cost today of an incremental unit of carbon (or equivalent amount of other greenhouse gases)[2] emitted now, summing the full global cost of the damage it imposes over the

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[2] Throughout this note, unless stated otherwise, references to 'carbon' are a shorthand for 'carbon dioxide, or an equivalent quantity of other greenhouse gases, with equivalence defined in terms of global warming potential'.

whole of its time in the atmosphere. It measures the scale of the externality which needs to be incorporated into decisions on policy and investment options in government.[3]

The SCC matters because it signals what society should, in theory, be willing to pay now to avoid the future damage caused by incremental carbon emissions.[4] We should be willing, as a society, to make changes in our economy which generate emissions savings which cost up to and no more than the damage we expect the emissions to cause, because to do so would make society better off.

Because the amount of damage done by each incremental unit of carbon in the atmosphere depends on the concentration of atmospheric carbon today and in the future to which it is added, the SCC varies depending on which emissions and concentration trajectory the world is on.

The SCC is conceptually different from:

- the market price of carbon – which reflects the value of traded carbon emissions rights to those in the market given the constraints on supply of these rights to emit imposed by current policy (e.g. through EU ETS); and

- the marginal abatement cost (or MAC) – which reflects the cost of reducing emissions (rather than the damage imposed by creating emissions).

Under certain restrictive assumptions, the three measures would be broadly equal, at the margin. For example, if the carbon market covers all emissions and is competitive, then the market price will be equal to the MAC for a given target. Further, the MAC will be equal across all emitters to reach a given reduction target, which is the condition for cost-effective policy. Optimal policy requires in addition that the target is set such that the MAC is equal to the SCC, as is discussed further below.

How should we use the SCC to determine a stabilisation goal?

From an economic perspective, the optimum stabilisation goal would be at the carbon concentration level for which the SCC was equal to the MAC required to

[3] An externality is a cost or benefit conferred upon an agent who was not party to the transaction. The presence of externalities leads to a sub-optimal allocation of resources as the full costs to society are not taken into account in agents' decision-making. Emissions of GHGs are an externality, since they impose costs upon global society which are not taken account in individual agents' decisions. For a discussion of externalities relating to climate change, see Nordhaus, William D., 6th Annual Conference*:* ""Global Public Goods and the Problem of Global Warming"", Toulouse, France, June 14, 1999., available online at: http://idei.fr/doc/conf/annual/paper_1999.pdf

[4] A social cost of, say, £20 per tonne of carbon dioxide means that emitting an extra tonne of carbon dioxide today has the same impact on society's expected welfare as reducing a representative consumer's consumption by £20 today.

incentivise the necessary abatement for the world to achieve the goal[5]. If the MAC required for a given goal was less than the SCC for that goal, then it would be cost-effective to abate further, and a lower stabilisation goal should be chosen. Similarly, if the MAC required for a given goal was above the SCC for that goal, a higher stabilisation goal and weaker abatement targets should be chosen.

Why use a shadow price of carbon, rather than simply the social cost?

In principle, we could use this process to set the goal and use the corresponding SCC for domestic and international policy assessment. However, two difficulties are encountered in adopting such an approach in practice:

- first, the stabilisation trajectory the world is on cannot be controlled by the UK alone, but is a function of global emissions. Setting an SCC for the UK therefore involves making assumptions about the actions of other countries;

- second, despite recent advances in modelling, there is considerable uncertainty about the SCC associated with any particular stabilisation goal, and there is no guarantee that this value will be sufficient to incentivise the necessary abatement to attain that goal. There is also uncertainty – albeit to a lesser extent – regarding the MAC for a particular goal, since this depends on assumptions about the availability of global abatement options and technological change in the future.

For either of these reasons, the SCC associated with any given stabilisation goal and the MAC needed to achieve it may not be equal. In this case, using the SCC associated with the selected goal may under- or over-deliver carbon abatement. For example, if the SCC for the goal is less than the global MAC for the goal, and the SCC is used in appraisal, then too little abatement will take place to reach the goal.

The rest of this note sets out our approach to dealing with these two issues, now and in the future, through the use of what we call the shadow price of carbon (SPC). As is explained in greater detail below, the SPC is based on the SCC for a given stabilisation goal, but can be adjusted to reflect:

- estimates of the MAC required to take the world onto the stabilisation goal; and

- other factors that may affect UK willingness to pay for reductions in carbon emissions, such as political desire to show leadership in tackling climate change.

Therefore, whereas the SCC is determined purely by our understanding of the damage caused and the way we value it, the SPC can adjust to reflect the policy

[5] For a dynamic optimal solution, the MAC and SCC must be equal not just in the present, but also through time.

and technological environment. This makes the SPC a more versatile concept in making sure that policy decisions across a range of government programmes are compatible with the Government's climate change goals and commitments.

Choosing the appropriate shadow price of carbon for the UK

As noted above, the SCC varies depending on which emissions and concentration trajectory the world is on: the higher the concentration, the higher the SCC, since there will be more damage from climate change. Choosing an SCC for the UK therefore involves making assumptions about the future policy of the rest of the world.

The Stern Review suggests that the optimum stabilisation goal requires the world to aim for atmospheric concentration somewhere in the range 450-550ppm CO_2e.[6] In order to conclude that it is worth acting, each country needs to be confident that enough other countries are committed to a similar goal. Commitments under Kyoto and emerging post-Kyoto consensus on emissions caps in the EU, combined with emerging climate change policies in other countries[7] abroad, mean it is now much more likely that the world will do something significant about global warming than that it will do nothing. Whether this is consistent with the stabilisation goal advocated by Stern is not yet clear, but for the purposes of decision making in the UK this is the most reasonable assumption to make.

Adopting a SPC higher than this range would imply a presumption by the UK (or any other country) that other countries would not move to achieve a goal of 550ppm CO_2e or lower. With the UK accounting for only 2 per cent of global emissions, even more aggressive UK action could not compensate for lack of commitment elsewhere. Using a higher SPC in investment appraisal than implied by a path to 550ppm CO_2e would induce additional, more costly abatement measures in the UK, so that the UK undertook greater reductions in carbon emissions than would be efficient to contribute to a 550ppm CO_2e goal or lower. More generally, it would be incorrect to choose a SPC based on a SCC which current evidence places outside the suggested range.

Within the Stern range, the tighter the emissions target, the lower the SCC will be, since there will be less damage from climate change. Thus in Stern's suggested range, the SCC is highest for 550ppm CO_2e. Care is therefore needed in selecting the specific target on which to base the UK's SPC. If the SCC exceeds the required MAC for the given goal, this will lead to over-achievement of the target. However, if the SCC is below the MAC for the expected stabilisation goal, then

[6] Stern Review, Chapter 13: "The current evidence suggests aiming for stabilisation somewhere within the range 450 - 550ppm CO_2e. 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, not least because of past delays in taking strong action."

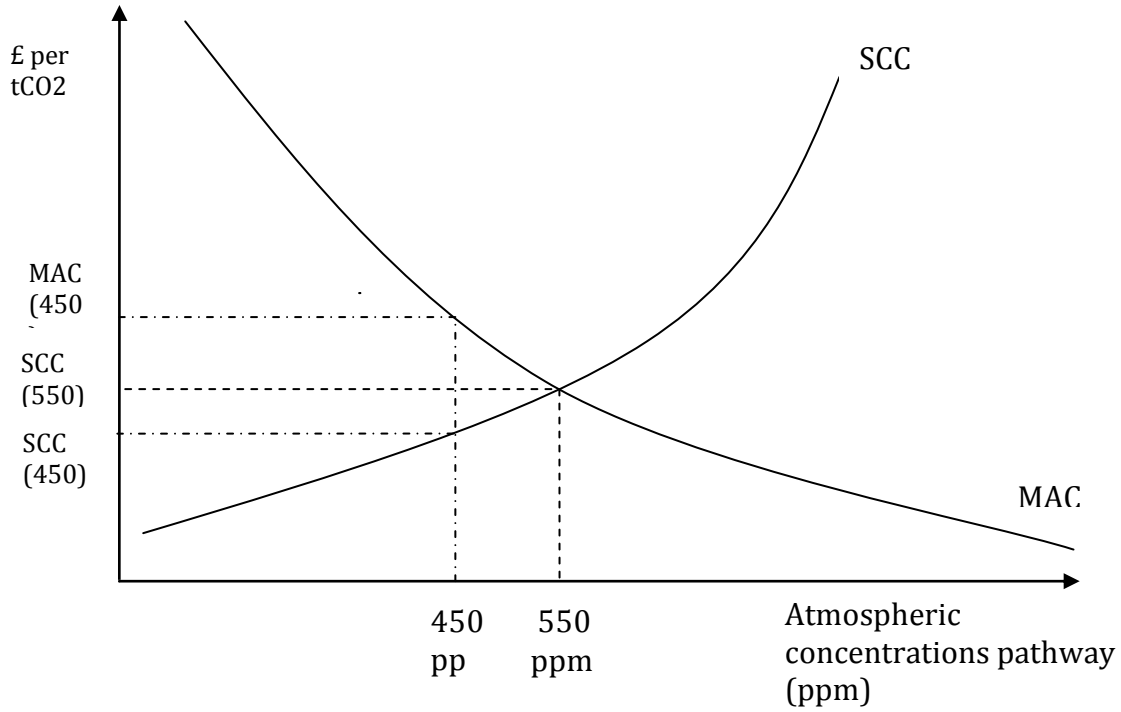
[7] For example, in the US and substantial progress planned in China's 11th Five-Year Economic Plan .

decisions taken on the basis of the SCC will fail to reach the expected goal – too little investment will take place. . For this reason, and in order to be more certain that the UK is undertaking sufficient abatement to help achieve the stabilisation goal, we believe it is prudent to adopt a SPC based on the SCC at the top of the 450-550ppm CO_2e range.

This is illustrated in figure 1 below. The MAC curve shows the marginal abatement cost that is required to bring about the emissions reductions that will allow a given stabilisation pathway to be reached.[8] For illustrative purposes, the diagram below assumes that 550ppm is the optimal goal – i.e. the social cost of carbon associated with stabilisation at 550ppm is also equal to the MAC required to reach that stabilisation pathway.

The diagram also shows the SCC for stabilisation at 450ppm, which in this example is below the MAC required to reach the 450ppm pathway. As a result, adopting a target based on the SCC at 450ppm will not provide sufficient incentives to undertake the abatement required to reach the 450ppm pathway. In fact, in this case adopting an SCC for the 450ppm pathway will lead to stabilisation somewhere in excess of 550ppm.

Figure 1: Comparison of SCC and MAC Associated with Different Stabilisation Goals



[8] This exposition is not identical to a traditional marginal abatement/marginal damage diagram which would have the x-axis measuring quantity of emissions. In the traditional approach, the MAC curve represents the additional cost of reducing emissions by one unit. Here we take the MAC as a more dynamic concept – it measures the price that is required to produce the emissions reductions that will lead to the atmospheric concentrations pathways on the x-axis.

Therefore it is important to note that the rationale for adopting an SCC value corresponding with the top of the stabilisation range is to ensure that abatement is generated compatible with moving into the 450-550ppm proposed range. It does not imply acceptance of 550ppm as a target, rather than a lower stabilisation goal. [9]

These three arguments – that:

> (1) it is sensible to assume that the world will take substantial action towards an upper stabilisation goal limit of 550ppm CO_2e;
>
> (2) using an SPC consistent with atmospheric concentrations above 550ppm CO_2e would lead the UK, or any other individual country to do 'too much' relative to other countries and to the goal; would not reflect progress made from business-as-usual, and would ignore the evidence that the optimum range is 450-550ppm; and
>
> (3) adopting an SPC consistent with concentrations below 550ppm might lead us to do too little, given current uncertainties;

- lead us to the conclusion that we should adopt a social cost of carbon consistent with the damage experienced under an emissions scenario which leads to stabilisation at 550ppm CO_2e.

The Stern Review calculates that this implies a social cost of carbon of $\$30/tCO_2e$ in 2000, equivalent to $£19/tCO_2e$.[10] This is therefore the number we believe should be adopted as the basis for a shadow price of carbon (SPC) profile for use in policy and investment appraisals across government in the UK.[11] Using the uprating conventions set out below, we adopt an SPC in 2007 of $£25/tCO_2e$.[12] The SPC applied in appraisals should be specific to the year in which carbon is emitted (or abated).

Incorporating abatement costs

The above analysis is based purely on evidence relating to the SCC– that is, the damage costs of an additional tonne of carbon at different concentration ranges.

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[9] As noted in the Stern Review, it makes sense to adopt an SCC consistent with a particular goal only if that SCC is sufficient to bring forward the abatement required to reach that goal. This would suggest erring on the side of caution by adopting the SPC from the top of Stern's suggested stabilisation range.

[10] Stern Review, Chapter 13. See annex for currency conversion factors; sterling figure here uses long-run market exchange rates. This SCC compares with a SCC for business as usual of around $\$85/tCO2e$, or $£53/tCO2e$.

[11] This is a central estimate for the SPC. A range of +20%/-10% should be applied to the new SPC (please see below for further details).

[12] Year 2007 values based on year 2000 values plus GDP deflator to take account of actual inflation since 2000. We adopt a long-run average exchange rate, whereas Stern uses the year 2000 exchange rate consistent with the price base used throughout the Review. Our estimate of the SCC is therefore around 20 per cent lower than it would have been had we applied the Stern Review exchange rate.

However, it is also prudent in setting the SPC to reflect the best available information on the level of abatement costs which would need to be incurred in order to meet a given abatement and / or stabilisation goal (itself informed by the global SCC and MAC). This is an alternative to the SCC-based approach (but, as discussed above, is equivalent to it at the optimum stabilisation goal). The advantage of this approach is that it should provide greater assurances that the goal in question can be reached in practice through measures incentivised through the SPC. It again involves a number of assumptions regarding, for example, the nature of the global effort to tackle climate change (which will affect the availability of global abatement options) and technological change.

On the assumption that global emissions caps will be adopted in the near future, covering all sectors and abatement options, and that all emissions can be traded between countries, then the MAC for the UK should in principle be equal to the global MAC. The UK would then have the option of supporting mitigation policies wherever in the world the lowest cost abatement options exist, either through importing EU emissions permits, the clean development mechanism or through other international mechanisms designed to achieve efficient abatement across the world. Such mechanisms would in principle allow global abatement targets to be reached at the lowest overall cost.

Under such assumptions, global MAC curves provide an assessment of what the price of carbon would need to be for a given level of abatement to be delivered globally, providing this can be achieved efficiently, with perfect international cooperation. There has, until recently, been limited data on which to base such an assessment. However, McKinsey have developed global MAC curves for 2030, in the first microeconomic investigation of its kind to cover all greenhouse gases, sectors and regions[13]. These curves provide evidence about the necessary minimum carbon prices to support 400ppm, 450ppm and 550ppm stabilisation in 2030. They estimate that in 2030 a stabilisation target of 550ppm would require a carbon price of 25 Euros a tonne of carbon dioxide, and a target of 450ppm would require a carbon price of 40 Euros a tonne (all in 2007 prices).

40 Euros / tonne CO2e is roughly the same as our proposed SPC for 2007 of £25 / tonne CO2e, implying that the SPC is broadly consistent with reaching stabilisation at 450ppm.[14] However, the 40 Euros / tonne CO2e figure would apply in 2030, when, through the uprating conventions set out below, our SPC would have reached £40 / tonne CO2e – a figure some 50% higher. This does not necessarily imply that the SPC we have adopted is higher than that required to reach 450 ppm. The calculation above requires comprehensive international action, and perfect exploitation of the abatement potential available globally. If

[13] Available at: http://www.mckinsey.com/clientservice/ccsi/pdf/Cost_Curve_for_Greenhouse_Gas_Reduction.pdf

[14] Taking into account the above discussion of the SCC and MAC for a given goal, it is important to note that the rationale for considering the MAC value corresponding with the bottom of the stabilisation range is to help ensure that abatement is generated compatible with moving into the 450-550ppm proposed range. This is essentially the same reasoning that led to the choice of an SCC value at the top of the stabilisation range.

this ideal system is not adopted, the actual MAC required may be substantially higher than this figure. Moreover, if a supplementarity condition is imposed (stipulating that a certain proportion of abatement must take place within UK borders) this will raise the MAC (for the UK) required to reach the concentration goal.

There are two recent estimates of UK MAC curves that can be drawn on in seeking to understand the costs of abatement in the UK: one calculated for the Energy White Paper[15] and the other by McKinsey.[16] The MAC curve presented in the 2007 Energy White Paper suggests that the SPC is of a magnitude that would approximately incentivise the necessary abatement to reach 2020 targets[17]. On the other hand, subsequent work by McKinsey to estimate a MAC curve for the UK suggests that the MAC to meet 2020 targets using domestic abatement alone would be significantly higher than that implied by the global MAC curve.[18]

In conclusion, available evidence provides some indication that the SPC is broadly in line with meeting the 450ppm goal providing full international abatement options can be exploited, although the figure will depend on the degree of abatement required to take place in the UK. Further work is required to conduct a more thorough assessment of global and UK MAC curves, including the assumptions they incorporate about technological change. This is a priority area of work for the short and medium term, leading up to the first review of the SPC in a year's time, as set out below.

The value of leadership

The UK Government's position on leadership may affect the SPC desirable for the UK. Attaching value to leading on climate change mitigation - whether as a contribution to reaching global agreement, or to gain some first-mover advantage – increases the UK's willingness to pay. This is distinct from the underlying damage imposed by the incremental unit of carbon – reflected in the SCC – and is another reason for adopting a shadow price (SPC) in the future which is based on, but not necessarily the same as, the SCC.

Indeed any country that attached a higher value to (avoiding) environmental damage might prefer a higher SPC. Nevertheless, in global terms, cost effectiveness would still require a common carbon price, so, in principle, there would not be scope for different valuations in practice once a comprehensive

[15] Available at: http://www.berr.gov.uk/files/file39387.pdf

[16] See Climate change: Everyone's business. A report from the CBI Climate Change Task Force. Available at http://www.avtclient.co.uk/climatereport/docs/climatereport2007full.pdf

[17] It should be noted, however, that there are potential issues around baselines and potential abatement on this curve that require further analysis. The MAC curves discussed here, and their relation to the SPC, should therefore be seen as illustrative at present and the drawing of strong conclusions should be avoided.

[18] The McKinsey study found that 90 – 95 % of the target could be reached at a marginal price of €60 - €90 / tCO2e (approximately £40 - £65/tCO2e at prevailing exchange rates).

global agreement was in place. Leadership may instead be demonstrated in the willingness to take unilateral action in order to spur global agreement.

Does the shadow price of carbon change over time?

Assuming that we are aiming for a specific stabilisation goal, the SPC might vary over time for several reasons – some of which cause changes in the SCC, and some of which are additional to changes in the SCC.

- As time goes on, the damage comes closer, and is discounted less heavily; so its present value rises, increasing the SCC.

- The concentration of carbon in the atmosphere is rising towards its long-run stabilisation level, and expected climate-change damages accelerate with higher concentrations. An extra unit of carbon will do more damage at the margin the later it is emitted because, even with a plausible concentration goal, it will be in the atmosphere while concentrations are higher and higher concentrations mean larger climate-change impacts at the margin (as damage is a function of the cumulated stock); this too increases the SCC.[19] Additionally, as incomes grow, so the monetary value of damage is likely to grow, owing to an associated higher willingness to pay to avoid warming damage[20]

- Refinement of the science or assumptions underlying the damage cost function will also change the level of the SCC. For example, the incorporation of socially contingent impacts into the modelling would increase the SCC.

- New information about the likely costs over time of mitigation) may justify increasing or reducing the SPC, independently of any changes in the SCC (which is purely related to damages). Likewise the SPC may be raised if there is evidence that the value applied is inadequate to deliver the UK's contribution to the global stabilisation goal agreed to be desirable.

- The SPC will change to reflect general changes in the price level, as will the SCC.

[19] More strictly speaking, temperatures are log functions of concentrations, but damages are convex functions of temperatures. For the SCC to rise, ceteris paribus, the second effect must outweigh the first (assuming constant income levels).

[20] David Pearce "The Social Cost of Carbon and its Policy Implications" *Oxford Review of Economic Policy,* 2003. Vol 19:3, pp 362-384

We propose that the value of the shadow price of carbon is:

- uprated each year by 2 percent a year reflecting the Stern Review's assessment of the rising incremental damage of each unit of carbon as temperatures rise;[21]

- also uprated each year to the year of emissions abatement/release by the GDP deflator (and for future years, by the Government's central inflation target of 2 per cent a year if values in nominal terms are required) – this is so that all costs and benefits being appraised are based on the same year's price level; and

- reviewed in full every five years, in line with the five-year target setting periods specified in the Government's Climate Change Bill,
    - to capture better understanding of the science and damage cost functions;
    - to reflect changes in the effective world stabilisation goal and progress towards it; and
    - to reflect an assessment of whether the SPC profile, based on the SCC in conjunction with evidence on the marginal abatement cost curve, will generate abatement consistent with the UK's commitments.

Recognising that this is a new approach and that there are particular uncertainties in the first period about the level of the MAC required to reach a particular goal, we will review data on marginal abatement costs (UK and international), and reassess the SPC in light of this within a year. This will ensure that we establish a robust basis for the SPC for use in the process of setting the UK's first carbon budgets in 2011. Subsequent reviews will take place at five year intervals in line with the carbon budgeting review periods.

How should the shadow price of carbon be applied?

The SPC should be incorporated into policy and investment appraisals in the same way as any other cost or benefit. It should be incorporated consistently into all analysis to support decision-making. Plainly this applies when choosing among alternative carbon abatement measures. But it also applies to all other option appraisals which have a significant carbon impact.[22]

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[21] The standard version of the PAGE model would indicate an annual increase in incremental damage costs in excess of 2 per cent. The model's owner, Chris Hope, suggests in a letter to the Financial Times that an annual increase of up to 3 per cent would be appropriate. Due to the uncertainty around this, we have opted for a 2 per cent increase which can be reviewed when the SCC is, periodically.

[22] If anything it is more important that the SPC is incorporated making choices between policies or measures whose main purpose is not carbon reduction. Carbon benefits will be explicitly factored into policies whose main purpose is carbon abatement – and incorporating the SPC into the cost-benefit analysis is equivalent to a cost-effectiveness analysis in which carbon abatement is the denominator. For policies where the primary policy objective is not carbon abatement, the SPC allows carbon impacts to be taken into account on a basis consistent with other costs and benefits in assessing the net present values of alternatives.

The SPC must be applied consistently, in all areas of government decision-making

The effect of the SPC will be to raise the net present value (NPV) of options with low carbon impacts relative to those with larger carbon impacts (or for carbon abatement policies, the SPC will raise the NPV of policies with larger carbon savings relative to those with lower carbon savings) so that other things being equal the carbon emissions associated with policy delivery will fall. It is important that the SPC is applied consistently and universally across decisions in government with significant implications for emissions of carbon and other greenhouse gases, so that we minimise the overall cost to the UK economy of meeting its obligations consistent with delivering a 550ppm CO_2e stabilisation goal.

So, for example, if low-cost abatements can be achieved through capital programmes for local authorities, schools, hospitals or the central government estate; or by selecting one portfolio of transport spends rather than another; incorporating the SPC into appraisals should ensure that options and projects are ranked in a way which gives due weight to carbon they emit or abate. Failing to do this consistently across government may mean that the cheapest carbon reductions do not happen.

The Better Regulation Executive and the Department for Environment, Food and Rural Affairs (Defra) will, at regular intervals, jointly review Impact Assessments from all UK government departments to give assurance that the value of the change in greenhouse gas emissions has been appropriately factored into decisions, wherever options have a significant impact on greenhouse gas emissions.[23]

What is an appropriate range?

In appraisals it is standard practice to apply a sensitivity range to the values for key parameters. For the new SPC, a sensitivity range of +20%/-10% should be applied. This range is narrower than the previous range around the SCC as: (1) some of the risks and uncertainties associated with the damage function are reflected in the cost modelling which underpins the $30/tCO2e number; (2) the use of a wide range has hindered decision making; it is much better to use a consistent central number based on our best judgement and on the conclusions from Stern to derive NPVs and rankings for policy options.

It is right that those wanting to impose significantly higher costs than are implied by the central estimate and the narrower range are compelled to be explicit about the rationale (which may for example be that there is an option value associated with building in flexibility to long-lived assets; or a market failure rationale not reflected in carbon externality).

[23] Guidance on impact assessments (updated April 2007) is available at http://www.cabinetoffice.gov.uk/regulation/ria/ indicates that the value of the change in greenhouse gas emissions must be quantified and included on the cover sheet

We can also be more confident in applying a narrower range than previously as some of the MAC data considered would suggest that the SPC is roughly in line with that which is required in terms of policy-consistency. As our knowledge of the MAC curve improves, uncertainty and thus the applicable SPC range should fall.[24]

The three legs of the policy framework

The Stern Review concludes that action to tackle greenhouse gas emissions requires action in three areas, reflecting three separate market failures. This is because Stern recognises that carbon intensive activity is characterised by, broadly, three different market failures.

- The carbon externality. When a polluter makes the decision of whether to emit, s/he does not take into account the cost their actions will have on the environment. The social cost of carbon (SCC) is a monetary estimate of the cost imposed upon society by GHG emissions.

- Innovation market failures. There are a number of reasons why, even with a carbon price, the market would undertake less innovation in low carbon technologies than society would desire. This is because of the presence of a range of innovation market failures.

    - *Knowledge spillovers*. It is sometimes not possible for an innovator to capture all the returns from innovation. Once new information has been created, it is almost costless to pass on. Thus – if mechanisms such as intellectual property rights fail to capture the full benefits of an innovation – individuals and businesses in the market will not be incentivised to innovate at the socially optimal level.
    - *Infrastructure barriers*. Clean technologies may require new infrastructure to operate.
    - *Market structure*. Markets occupied by multiple small producers may be ill-equipped to invest in R&D while firms in highly regulated markets may be faced with lower incentives to invest.
    - *Risk and urgency*. The uncertainties and risks of climate change are of a scale and urgency not reflected in the decisions of private investors.

Policies to tackle innovation market failures will help to lower the MAC curve in future, increasing the efficient level of abatement that is associated with a given level of the SPC.

- Other market failures and barriers to changing behaviour. Even with a carbon price and technology policy in place, some low cost abatement

[24] Although clearly future technologies will always remain uncertain however much knowledge is acquired.

may not be undertaken because of the existence of other market failures/barriers such as information asymmetry, capital constraints, misaligned incentives, habitual behaviour, etc. Policies to act on such problems should increase the response to carbon pricing, so that a larger proportion of adjustments for which the MAC appears to be below the carbon price occur in practice.

It is important to act on all three market failures, and not on the internalisation of the carbon externality alone. The objective is to ensure the costs of effectively mitigating climate change remain as low as possible.

Assessment of interventions to tackle innovation market failures should take into account the likelihood that (i) the resulting technology will have a MAC below the SPC; and (ii) the expected total public and private cost of development and deployment is less than deploying an existing technology to achieve the same reductions. If this is not likely, then the cost-benefit test will not be passed. An intervention under the third leg would be justified where it led to cost-effective abatement opportunities being taken up which would otherwise be missed. In such cases, by definition, the MAC including policy costs (administration, etc) must be less than SPC; if not, the policy should not be pursued on climate change grounds (though other factors, e.g. air quality benefits, need to be taken into account). Ideally, interventions to deal with non-carbon market failures should also be technology-neutral in order to reach a given level of emission reduction at lowest cost.

Least cost, first

Subject to this, it is important to remember that the SPC is not the same as the cost or price paid for emissions reductions. It is simply a measure of our willingness to pay for carbon abatement. Projects or policies should be selected on the basis of the net present value incorporating the SPC, having first allowed for policies to tackle market failures in research, development and deployment (RD&D), and if appropriate to catalyse changes in behaviours and attitudes (as summarised in Annex 3.)

After the market failure has been identified and the appropriate instrument selected to address that market failure, the cheapest abatement (or highest NPV) options – i.e. the most cost effective options - should generally be chosen first. The abatement cost of such projects is likely often to be substantially lower than the SPC; and abatement should continue up to the point at which the abatement cost for the marginal project equals the SPC. Unless justified by a clear RD&D or behavioural change rationale assessed as just described (where these are not factored into the MAC), the marginal cost of abatement should not exceed the SPC.

Least cost, first implies a movement up the MAC curve over time as mitigation increases in magnitude. Other things being equal, this implies an increase in the MAC. However, there will also be improvements in technology which will shift

the MAC curve down over time. While the marginal abatement cost is likely to be rising over time, it is possible that the average abatement cost over all emissions reductions may be falling.

What about the discount rate?

The Stern Review argued:

- that the social rate of time preference is relevant only for marginal analysis, and therefore is not applicable in taking non-marginal decisions on whether or not to avoid dangerous climate change; and

- for a particular ethical perspective on discounting – essentially that it is unethical to discriminate against future generations simply on the basis of their date of birth, and that the pure rate of time preference should therefore reflect only the small risk that the planet and humanity will cease to exist.

The second point has been extensively debated since the publication of the Stern Review, though Stern's broad conclusions have been welcomed by the Government. Our view is that two approaches to discounting are appropriate in incorporating the SPC into economic appraisal.

- The Stern approach is appropriate in assessing the current generation's willingness to pay to avoid the impacts of climate change in the future – this is a non-marginal decision – and that is therefore what the SPC used in current decision-making should reflect.

- However most (perhaps all) individual policy decisions which impact on our emissions are at the margin. In assessing the present value of future streams of costs and benefits, therefore, the approach described in the Green Book should be used.[25]

This means that, in appraising individual policy and investment options, the SPC should be used to value carbon emissions and abatement (reflecting the value of non-marginal impacts) and all costs and benefits should be discounted as the Green Book proposes, using the standard 3.5 per cent discount rate (reflecting the marginal nature of these individual decisions).

This approach reconciles the need to reflect the non-marginal nature of the decision to avoid dangerous climate change with the marginal nature of individual projects and policies.

[25] It is possible that the Stern approach to discounting has implications for other areas of policy where non-marginal decisions come into play; and where there are significant intergenerational effects. However we do not make judgements on this point in this note.

Avoiding double counting: internalise only the externality

The shadow price of carbon is set primarily on the basis of the social cost of carbon, with adjustments to reflect target-compatibility. It is principally a social cost concept. The SPC should therefore be applied so that the externality associated with damage arising from greenhouse gas emissions is internalised. In producing policy and project appraisals we need to be careful to make sure that externalities are not counted twice. Where policy/project costs already reflect – wholly or partly – the social cost of carbon, only the remaining external part of the SPC should be added. This might arise where another policy instrument internalises some part of the SPC – for example through a tax or where the price of emissions permits is factored into energy price projections. Failure to take account of carbon costs already internalised will give too much weight to carbon impacts.

In these cases, the general approach should be to exclude any taxes or transfers from the cost-benefit analysis (as described in the Green Book). This approach should also be taken for the cost of obtaining permits or other payments under an emissions trading or equivalent scheme, where the market value of emissions simply reflects the impact of a government intervention which has the express purpose of reflecting an externality. For these purposes only, the creation of a market by capping and trading emissions can be regarded as analogous to a tax, and should therefore be treated as a transfer payment. Note that where such a price is imposed 'upstream' of the project being assessed, it may already be factored into input prices (e.g. electricity costs), in which case this element of the input price should be removed. If in doubt, Defra's Climate Change Economics team[26] should be consulted and will advise on the approach to be taken.

Relationship between SPC and market instruments

In a cap-and-trade system, abstracting from the impact of other market imperfections[27], we would expect to see carbon constrained so that rights to emit traded at prices up to the SPC, but reflecting the balance between the demand for emissions and the supply of abatement options (with the MAC likely to be below the SPC for many discrete options). Under a hypothetical optimal carbon tax, the tax rate would be set equal to the SPC; but adjustment (abatement) costs actually incurred would reflect lower marginal abatement costs. Carbon tax revenues count as a transfer, not a cost. In either case, improving technology over time is likely to lead to a falling marginal abatement function over time.

[26] Email economics@defra.gsi.gov.uk

[27] The carbon trading system could be designed to generate a higher price than the SPC to address innovation externalities, or the danger that lack of perfect competition might distort the market.

What is the relationship between the SPC and cost-effectiveness?

This paper focuses on the definition and use of the SPC in cost-benefit analysis. However, cost-effectiveness analysis is also used in policy design, particularly at the portfolio level[28]. Cost-effectiveness analysis estimates for each technology or policy option the unit cost of abatement per tonne of carbon dioxide or equivalent greenhouse gas; and ranks abatement options in ascending order of unit cost (netting off ancillary benefits). To minimise the costs of abatement for a given target, options can be selected in order of cost-effectiveness, until sufficient options have been taken up to deliver the targeted abatement. Cost-effectiveness analysis is the main framework used in the UK to design and assess possible portfolios of carbon abatement policy options which deliver our abatement targets at minimum cost.

In principle, with a common set of abatement options and assumptions on costs and benefits, cost-effectiveness and cost-benefit analysis approaches will lead to the same ranking of options.

In practice, however, a cost-effectiveness ranking of policy options designed to reduce carbon emissions will invariably omit the large number of policy measures for which carbon abatement is not the primary goal, but which nevertheless have a significant influence on emissions. Many thousands of individual decisions across the public sector fall into this category – including decisions on the planning framework, infrastructure projects, the construction specification of schools and hospitals, and the configuration of transport projects. It is unrealistic to assume that all of these decisions can be reflected in, and influenced by, a single cost-effectiveness analysis.

However the inclusion of the SPC in the appraisal for each decision ensures that the carbon impact of each option is explicitly reflected in its net present value, on a basis consistent with emissions targets. This means that the SPC helps to ensure that the Government's carbon abatement goals are reflected in the full range of decisions across the public sector, and not just in those for which carbon abatement is explicitly the main purpose. Moreover cost-effectiveness analysis can be revised as the appraisal process identifies cost-effective abatement options across the broad range of policy and investment decisions.

Embedding the SPC into policy and project appraisal across government therefore complements the use of cost-effectiveness analysis in developing an optimal portfolio of abatement measures.

[28] In, for example, in the UK's Climate Change Programme Review (2006) and the Energy White Paper (2007).

What about other greenhouse gases?

Other greenhouse gases should be given equivalent treatment to carbon, with the SPC per tonne being set equal to the SPC per tonne of carbon for a given year (the year of the GHG emission) multiplied by the relevant global warming potential (which is shown in Table 1), and the profile of emissions. E.g. for methane released in 2010, the SPC per tonne would be the SPC in 2010 multiplied by the global warming potential of methane. This figure would then be multiplied by the number of emissions of methane in that year. Such a calculation should be performed for all emissions of GHGs in all years.

Table 1: Greenhouse Gas Global Warming Potentials to convert greenhouse gases to carbon dioxide equivalent and to find their Shadow Price of Carbon

Greenhouse Gas	100 year Global Warming Potential[29]
Carbon Dioxide	1
Methane	21
Nitrous oxide	310
HFC-23	11,700
HFC-32	650
HFC-41	150
HFC-43-10mee	1,300
HFC-125	2,800
HFC-134	1,000
HFC-134a	1,300
HFC-152a	140
HFC-143	300
HFC-143a	3,800
HFC-227ea	2,900
HFC-236fa	6,300
HFC-245ca	560
Chloroform	4
Methylene chloride	9
Sulphur hexafluoride	23,900
Perfluoromethane	6,500
Perfluorethane	9,200
Perfluoropropane	7,000

[29] The GWP figures listed in the table below are the 1995 Global Warming Potential values in terms of CO_2. Whilst the GWP have since been updated, the Kyoto Protocol states that "global warming potentials used by Parties [to the Protocol] should be those provided by the Intergovernmental Panel on Climate Change in its Second Assessment Report ("1995 IPCC GWP values")...".

Perfluorobutane	7,000
Perfluoropentane	7,500
Perfluorohexane	7,400
Perfluorocyclobutane	8,700
Carbon Dioxide as Carbon	3.67

Annex 1: Conversion factors and exchange rate assumptions used in deriving the SCC and SPC

The rate of converting carbon (C) to carbon dioxide (CO_2) is fixed at 12/44.

Using a long-run market exchange rates

Using an average of 1990-2005 PPP exchange rates (from OECD statistics) gives an average £/$ exchange rate of 0.622 (i.e. a $/£ rate of 1.61), making year 2000 values of Stern's estimates of the social cost of carbon:

$85/tCO_2 ≈ £53/tCO2 ≈ £194/tC
$30/tCO_2 ≈ £19/tCO2 ≈ £68/tC
$25/tCO_2 ≈ £16/tCO2 ≈ £57/tC

Using Stern's implicit exchange rate

In Box 13.1 of the Stern Review, conversion rates are given as:
£100/tC (2000 prices) = $116/tC (1995 prices) = $35.7/tCO_2 (2000 prices)

Leading to an implicit $/£ exchange rate of 1.309 (i.e. 35.7/(100*12/44)), making the year 2000 values of Stern's estimates of the social cost of carbon:

$85/tCO_2 ≈ £65/tCO2 ≈ £238/tC
$30/tCO_2 ≈ £23/tCO2 ≈ £84/tC
$25/tCO_2 ≈ £19/tCO2 ≈ £70/tC

Annex 2: Uprating convention and SPC profile in £/tCO_2, 2000 – 2050 (based on £19/tCO_2e in 2000).

Using long-run exchange rates gives a shadow price of carbon on a 550ppm CO_2e stabilisation trajectory of £19/tCO_2e in the year 2000. To account for observed inflation we use the GDP deflator for each year up to 2007[30] and increase by 2 per cent per year to account for the rising marginal damage cost over time.

Values given in real (2007) prices[31].

550ppm SPC using 1990-2005 market exchange rate and GDP deflator (£/tCO2)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
SPC with GDP deflator to 2007 and 2% pa increase	18.6	19.3	20.1	21.2	22.2	23.3	24.3	25.5	26.0	26.5	27.0	27.6	28.1

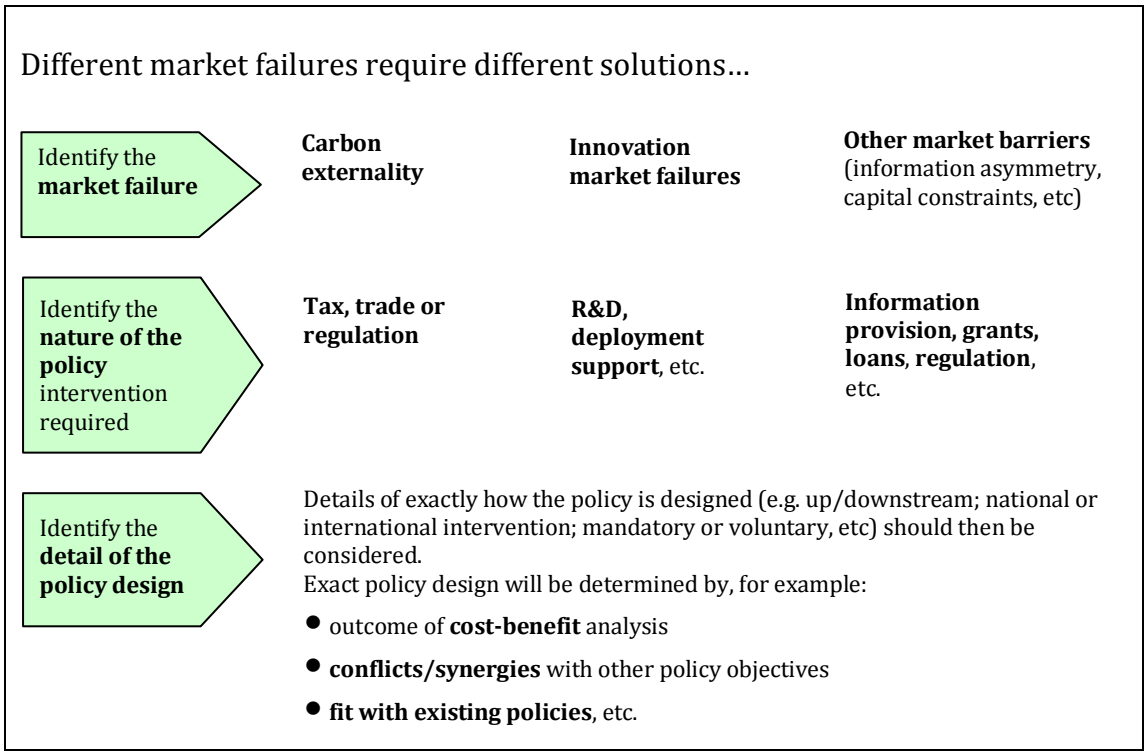
2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
28.7	29.2	29.8	30.4	31.0	31.6	32.3	32.9	33.6	34.3	34.9	35.6	36.4	37.1	37.8	38.6	39.4	40.1	40.9

2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
41.8	42.6	43.4	44.3	45.2	46.1	47.0	48.0	48.9	49.9	50.9	51.9	53.0	54.0	55.1	56.2	57.3	58.5	59.6

[30] Available from HM Treasury at http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_index.cfm

[31] All values in 2007 prices except 2000-2006 inclusive where the price level is the same as the year (i.e. 2003 SPC in 2003 prices) – this is only included for illustrative purposes to show how £25/tCO_2 in 2007 was reached. For appraisal where other costs/benefits in 2000-2006 price level, please consult Defra at economics@defra.gsi.gov.uk as the correct GDP deflator needs to be applied to the entire SPC schedule.

Annex 3: A summary of the least cost approach to policy formation



Source: Office of Climate Change