Certainty *versus* Ambition

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This paper is a revision of a paper entitled "Certainty versus Stringency" first presented to the Group in September 2001. It aims at weighing the value of greater flexibility provided by new commitment options against the certainty on emission levels provided by fixed targets.

- ***ACTION:*** *Delegates are requested to provide written comments and decide on possible release.*

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Executive Summary

A key issue for policy makers is how to choose a climate change policy that recognises the uncertainties in the costs and benefits of abatement actions, which will vary over time. Currently, there is no scientific or political agreement about exactly what concentrations of greenhouse gases could prevent dangerous interference with the climate system. How abatement costs will evolve in the future is also open for debate.

This paper reviews the economic literature relative to the choice of economic instruments applicable to climate change. In particular, it assesses whether "price" or "quantity" instruments, i.e. taxes and quantitative targets or quotas are equally effective when costs and benefits are uncertain. The literature suggests that if benefits grow faster than abatement costs when more abatement is undertaken, quantitative instruments are more efficient – i.e. minimise costs and maximise environmental benefits. If costs grow faster than benefits, taxes are more efficient. Hybrid instruments that combine quotas, a price cap and a price floor are always more efficient than either simple taxes or quotas.

Climate change is driven by the slow build-up of atmospheric concentrations of greenhouse gases. Thus, while the marginal abatement cost increases when more abatement is undertaken in any short period of time, the marginal benefit is likely to be more or less constant. The analysis thus suggests that taxes would fare better than quotas against climate change. The possibility of "climate surprises" is unlikely to significantly reverse this analysis, as long as the concentration thresholds that could trigger such phenomena are unknown.

Hybrid instruments combining a quantity and a price instrument (i.e. a price cap) may be attractive for a number of reasons. For example, they may be more attractive than taxes as they give governments more flexibility to distribute the abatement efforts through international and domestic allocation processes. Moreover, when abatement benefits are deeply uncertain (i.e. there is no best guess), hybrid instruments could encourage more ambitious quotas, as the price cap would lower the expected costs of abatement. More ambitious quotas would result in higher expected environmental benefits.

If benefits rise and costs decrease over time, preferences could change, i.e. in the future quantity instruments may be preferred because of their greater certainty in meeting atmospheric stabilisation goals. But hybrid instruments can be continuously modified to be closer to taxes or to quotas, through the adjustment of quotas and price cap levels, while keeping the framework constant. However, agreeing and implementing quotas and price caps at an international level may not be easy, and there is no guarantee that the international negotiation would lead to optimal outcomes.

Introduction

A growing body of literature considers new options for future action against climate change, including new options for quantitative commitments. These include dynamic (indexed) targets, non-binding targets (presumably for developing countries), targets with price caps, sectoral targets and others (for a review, see Philibert, 2005a).

A wide variety of options have been proposed for developing countries, addressing these countries' concerns about economic development as well as their institutional capacity. Fewer future commitments options have been proposed for industrialised countries, which are alternative to the Kyoto-type targets but still based on quantitative objectives. They include various forms of indexed or dynamic targets, and the introduction of caps on the price of carbon traded internationally.

Indexed targets would adjust assigned amounts to the evolution of some economic variables. Price caps would relax the emission objectives if the international carbon price reaches some agreed level. Thus, these options would by design reduce the uncertainty on the cost faced by countries that adopt such commitments – although their exact performance in this respect depends from concrete implementation. In so doing, they could facilitate the adoption of targets by a large number of countries.

It has also been argued that these more flexible options could facilitate the adoption of relatively more ambitious targets. On the other hand, these options offer a lower certainty that quantified emission objectives are fully met. This paper explores a possible trade-off between the certainty on emissions and the ambition of emission limits.

This paper focuses on price caps or, more generally, "hybrid instruments" made of emission limits, a price cap and a price floor. There is a small but growing literature analysing the efficiency of indexed targets (Jotzo and Pezzey, 2005; Sue Wing et al., 2006). It suggests that analyses of price caps could to some extent apply to indexed targets as well. However, indexed targets only alleviate uncertainties arising from uncertain economic growth – and even this is disputed (Philibert, 2005b, p.10). Hybrid instruments, by contrast, address uncertainties more globally (arising from economic growth, changes in the relative prices of energies, technology developments, etc). Quirion (2005) finds that *"in most plausible cases, either a price instrument or an absolute cap yields a higher expected welfare than a relative cap"*. There seems to be no straight comparison of indexed targets and price caps available in the literature yet.

The first section of the paper summarises the literature on economic instruments when pollution abatement costs are not known with certainty. The second section applies this analytical framework to climate change, looking at near term policies. The third section considers longer term issues, such as the implications of likely benefit rise and cost decrease over time, the risk of non-linear responses to the climate forcing or "climate surprises", and the ultimate objective of the UN Framework Convention on Climate Change. The fourth section considers how quotas and price caps could be negotiated and used in an international context. A conclusion summarises the key points and suggests possible future work on related topics.

1. Quantity instruments versus price instruments

This paper considers stylised economic instruments to limit pollution that are fully cost-effective, which might not exist in the real world. Price instruments or "taxes" should be thought of perfect proxy for marginal costs triggering economic agents' decisions in a straightforward way, ignoring perturbations that could result, e.g., from other taxes or market imperfections. Quantity instruments or quotas are envisioned as the support of frictionless global emissions trading systems achieving full flexibility in where emission reductions are achieved. Therefore, both instruments would equalise marginal costs of all emission reductions, achieving perfect cost-effectiveness.

If abatement costs are known with certainty, taxes and quotas would lead to the same outcome, at the same global cost. By fixing an emissions limit, the decision-maker would implicitly determine a carbon price, and vice versa.

1.1 Abatement cost uncertainty matters

The situation is different when abatement costs are uncertain, which is a common occurrence. In this situation, fixing quotas would lead to certainty on the environmental outcome, assuming full compliance. However, the costs of meeting this outcome would be uncertain. Alternatively, setting up taxes would leave the environmental outcome uncertain but provide certainty on the marginal cost. While uncertainty on total costs would be large with quotas, it would be largely reduced with taxes, which adjust the level of abatement to actual costs – lower marginal costs would entail larger amount of emission reductions and vice-versa.

In others words, both price and quantity instruments are equally cost-effective, i.e. for whatever result they produce they do so at the least possible cost. But they are not equally efficient in uncertain context, i.e. not equally able to match the marginal cost of the abatement policy with its marginal benefit (defined as the net present value attributed to avoided damages over an infinite future), and thus maximise its net benefits (environmental benefits minus abatement costs).

Following Martin Weitzman (1974), economists usually consider that the choice of economic instrument to address pollution problems, in face of uncertain costs, should essentially be based on a comparison of the policy's marginal benefit and marginal cost curves – leaving aside any other difference between the two instruments. Let us consider the two opposite cases:

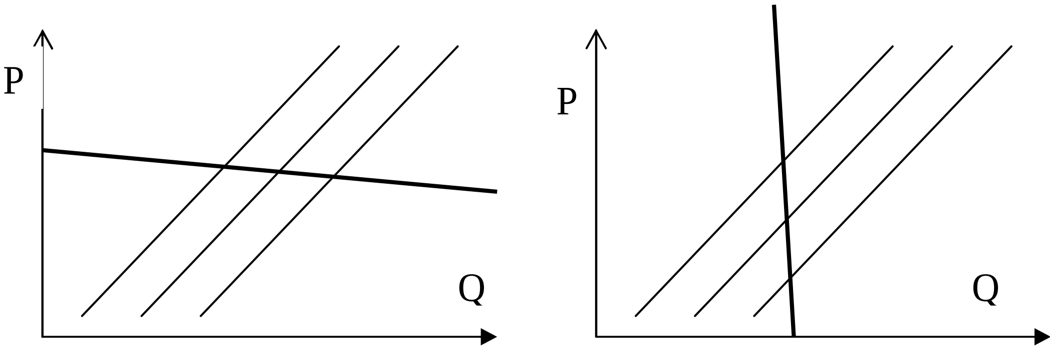
- Suppose the marginal benefit curve of the environmental policy is steeper than the marginal cost curve. The damage rapidly increases with the level of pollution. Then it is worth getting full certainty on the level of pollution, rather than risk suffering too much environmental damage. Quotas should be preferred in such cases.

- Suppose that, on the contrary, the marginal cost curve is steeper than the marginal benefit curve. The damage increases slowly with the level of pollution. A quantity instrument runs the risks of either triggering too high a marginal mitigation cost for too-low incremental environmental benefits, or too little mitigation if mitigation costs are low. Then it is preferable to get certainty on the marginal cost of abatement. Taxes should be preferred in such cases.

Following this general rule allows to minimise the social cost of the unavoidable mistake that will be made in deciding on the level of either instrument (fixing the price or fixing the quantity). As Jacoby and Ellerman (2002) have put it, *"the key to the choice is whether cost or benefit changes more rapidly as the level of emission control is varied"*.

Extreme cases make these results more intuitive. A catastrophe beyond some threshold in emissions with infinite damage would be an extreme case of the first situation. With a vertical benefit curve, a quantity instrument would be absolutely necessary. Constant marginal damage costs would constitute an extreme case of the second situation. With a flat horizontal marginal benefit line, a tax set equal to the estimated marginal benefit would ensure an optimal outcome regardless of the abatement cost curve. A price instrument would thus be the best choice.

Figure 1: Prices *vs* quantities



P stands for Price, Q for quantities of abatement. The origin figures the Business-as-Usual, uncontrolled level of emissions. Moving to the right, the quantity of abatement increases in a single period of time (please note that the horizontal axis does ***not*** *represent time). The bold line indicates marginal abatement benefits, the three other lines indicate marginal abatement costs: in the middle the curve that corresponds to the best-guess, on both sides two other possible outcomes. The decreasing marginal abatement benefit line reflects the hypothesis that marginal damage costs increase with the amount of pollution (from left to right).*

Figure 1 illustrates two polar cases for representation of benefit curves and uncertain cost curves. In both cases three possible cost curves set at 45° have been figured. Costs increase with the quantity of abatement undertaken in a single (short) period of time. On the left side of the figure, the benefit curve is almost horizontal, while it is almost vertical on the right. These “curves” are all straight lines, reflecting the usual assumption that (total) cost and benefit curves are quadratic, thus marginal cost and benefit curves are linear – they increase or decrease at constant rates. The optimal level of abatement is set at the intersection of marginal benefit and cost curves – beyond this point further abatement would cost more than the environmental benefit it would bring.

All values taken into account, what matters are the relative slopes of the two curves, as shown where they cross. On the left-hand side on Figure 1, suppose one fixes a price. It will, by construction, be close to what would have been the optimal price. On the right-hand side, the choice of quantity will by construction be close to what would have been the optimal quantity.

All other considerations apart, taxes ought to be preferred when the marginal cost curve is steeper than the marginal benefit curve, and quotas ought to be preferred when the marginal benefit curve is steeper than the marginal cost curve. An appropriate choice of instruments allows keeping dead-weight losses at their minimal after the uncertainty on costs is resolved, as more formally illustrated in the appendix on page 24.

1.2 When benefit uncertainty also matters

Uncertainty on the costs of environmental damages (or benefits of environmental protection) is rather common. However, if abatement costs were known with certainty, as stated earlier the policy maker knows with full certainty what pollution abatement a given tax level would deliver – or what cost an overall quota would impose on sources. Thus, uncertainty on damage costs (or benefits) does not matter in the choice of policy instrument, although that uncertainty will be taken into account in setting the level of any instrument.

However, Weitzman’s results are only valid if the uncertainties are sufficiently small to only affect the absolute values of costs and benefits but do not significantly affect their slopes. Section 3 will consider the possibility of non-linear climate impacts and how it might affect the choice of instruments.

Moreover, uncertainty on the environmental damage cost, especially when it seems “deep” enough – when there is no scientific agreement on the probabilities of distribution of the various possible outcomes – may increase the difficulty of agreeing on quotas. Some instruments may have a greater ability than others to accommodate diverging perceptions of the threat and thus help establish cooperative strategies when there is no single decision maker.

1.3 The superiority of hybrid instruments

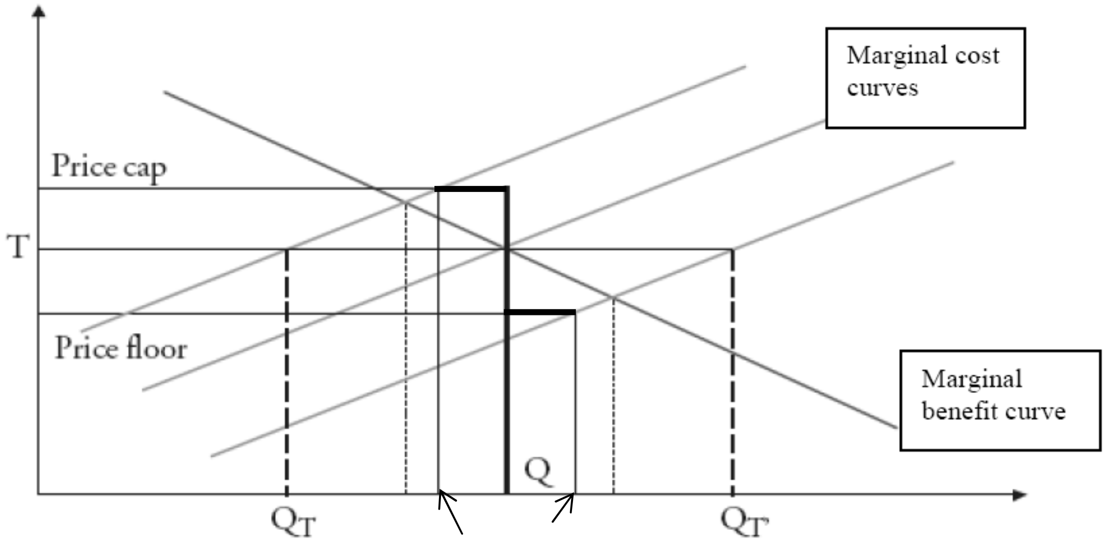
Elaborating on Baumol and Oates (1971) and Weitzman (1974), Roberts and Spence (1976) studied “hybrid instruments” that associate a quantity target, a price cap and a price floor. If abatement costs reach the price cap, governments sell additional permits at this price, less abatement is undertaken and emissions above the targets are “taxed”. If abatement costs go down below the floor price, governments buy permits at this price – thus subsidising additional abatement. Roberts and Spence showed that such hybrid instruments always perform better in maximising net benefits (environmental benefits minus abatement costs) than either pure instrument, as can be seen on Figure 2 below.

The economic advantages of hybrid instruments are especially significant when neither pure instrument clearly dominates over the other, i.e. when the two cost and benefit curves have similar slopes. If one pure instrument clearly dominates the other, a hybrid instrument offers only a small additional advantage. Other considerations – political economy, feasibility, practicability – would likely prevail for the final choice between hybrid instruments and the dominant pure instrument.

Cournède and Gastaldo (2002) have further explored hybrid instruments. They showed that the objective should be set at the same level than without price cap and floor, and that the price cap and the price floor should be set, respectively, in the upper and lower ranges of possible costs. How much higher and lower the cap and the floor should be than the best-guess cost estimate depends on the slope of the marginal environmental benefit curve. If the benefit curve is steeper than the cost curve, this distance will be large and the quantity will in most cases be fully met. If the cost curve is steeper than the benefit curve this distance will be small, narrowing the uncertainty around the price and increasing the probability that the instrument turns as a price instrument. In the extreme cases of vertical or horizontal benefit curves, the hybrid instrument turns into pure quantity of price instruments, respectively. This clearly appears as a generalisation of Weitzman’s results.

Cournède and Gastaldo (2002) also showed that if the establishment of a price floor is not desirable or feasible, a more ambitious target must be set under a price cap to compensate for the risk of underinvestment in abatement if costs turned out to be lower than anticipated. In other words, giving up some abatement if costs are higher than forecasted strongly reduces expected costs (before uncertainty is resolved), but also reduces expected benefits. Strengthening the target would restore a proper level of abatement and environmental benefits.

Figure 2: Hybrid instruments approximate the marginal benefit curve



P stands for Price, Q for quantities of abatement. The origin figures the Business-as-Usual, uncontrolled level of emissions. Moving to the right, the quantity of abatement increases in a single period of time. The emission reductions actually achieved (solid vertical lines, see arrows) when the costs are significantly higher or lower than forecasted are closer to the optimal pollution levels (dotted lines) than under a fixed quantity (bold line), are also closer to the optimal pollution levels than the quantities Q_T *or* $Q_{T'}$ *that the equivalent tax T would achieve.*

1.4 The case of "stock" externalities

The above-mentioned analyses assume that environmental damage comes from the flow of emissions. However, in many cases damages depend on the stock of pollution, i.e. its accumulation in the environment. Hoel and Karp (2001; 2002) and Newell and Pizer (2003) extend Weitzman's discussion of *Prices v Quantities* to the case of such "stock" externalities. All confirm Weitzman's results but adjustments are made for dynamic effects including discounting, stock decay and benefits growth. Newell and Pizer also take into account how abatement efforts made in one period influence, through technology developments, abatement costs in subsequent periods.

Newell and Pizer summarise their general results as follows: *"As long as the existing stock is large relative to the annual flow, marginal benefits will tend to look very flat over the range of annual emissions, since the reductions that could be taken in a given year will never be enough to significantly alter the stock. Based on Weitzman's relative slope argument, this generic characteristic (…) weighs heavily in favour of price instruments for their control. Our results demonstrate that this is true unless marginal benefits are high enough to warrant high abatement levels in the immediate future, or if benefits grow rapidly relative to costs."*

1.5 Instrument choice and policy ambition

Let us consider more closely the relationship between instrument choice and policy ambition, especially when the level of environmental benefits (e.g. avoided climate change damage) is also uncertain. To begin with, let us consider how cost uncertainty enters Weitzman's model. Cost is a function of the quantity of abatement undertaken; it is also affected by uncertainty. In other words, there is a best guess in the middle of an uncertainty range; any outcome within that uncertainty range is equally probable.

Let us now compare the "equivalent" tax and quota. Both would deliver exactly the same quantity if the best guess turned out to be right. Before uncertainty is resolved, however, they do not entail the same expected costs and benefits ("expected costs" and "expected benefits" are calculated by multiplying all possible outcomes with their probabilities of occurrence).

A tax entails lower expected costs than the equivalent quota, because less abatement is undertaken when costs are high (above the tax), and more when costs are low. But – taxes also reduce expected benefits. This arises from the decreasing marginal benefits when abatement increases – the possible environmental losses from lesser emission reductions are greater than the possible benefits from a symmetric increase in abatement.

The relative magnitudes of the cost savings and benefit losses of taxes versus quotas depend on the rates of increase of marginal abatement costs and marginal policy benefits. Comparing these rates indicates which instrument is the most efficient. If abatement cost rises faster than the benefit (when more abatement is undertaken), the savings of expected costs with a tax outweigh the losses of expected benefits – it is thus the right choice. If abatement benefit rise faster than the cost, the losses of benefits with a tax outweigh the saved costs– it would thus be a wrong choice and quotas should be preferred.

Let us consider further the case of roughly constant marginal benefits, where tax are clearly more efficient than quotas. Under best guess about costs, a quota could be chosen, or an “equivalent” tax. However, one may also define a higher tax level that would offer the same expected benefits than the “equivalent” quota. As marginal cost slope is steeper than marginal benefit slope, this tax will still entail lower expected costs than the “equivalent” quota.

One step further would be to adopt an even higher tax that would entail the same expected costs than the “equivalent” quota. This higher tax offers significantly higher expected benefits than the equivalent quota.

Between these two price levels, there is a range of tax levels that would all offer higher expected benefits at lower expected costs than the equivalent quota. Thus, when marginal benefits are thought to be flat, preferring a tax or a hybrid instrument instead over a simple quota allows defining a more ambitious policy that offers higher expected benefits for lower expected costs. There is thus a trade-off between the certain emission outcome of a quota, and the greater ambition a tax makes possible.

2. The Case of climate change: Near term analysis

How does this theoretical background apply to the case of climate change? Should this issue be dealt with – at least in theory – using taxes or caps? To try and answer these questions, this section reviews what is known or believed about the relative slopes of the marginal cost curve and the marginal benefit curve – and how uncertain these costs are.

2.1 Near term abatement cost curve: uncertain but steep

As Metz and van Vuuren (2006) state, *"Cost estimates are uncertain. This uncertainty is a consequence of uncertainty in baseline trends, effectiveness of policies, flexibility of economies to adjust to higher energy prices, technology development and assumed international policies."*

Numerous modelling results illustrate the breadth of mitigation cost uncertainty. For example, 13 models participating in the Stanford Energy Modelling Forum estimated the marginal cost of achieving the Kyoto Protocol objectives from less than $20 to more than $200 per tonne of carbon (Weyant and Hill, 1999).

Nevertheless, marginal abatement costs are likely to grow along with the quantity of abatement required in any fixed, short period of time. No-regret options are not unlimited. After they have been tapped, costs will become positive and are likely to progressively increase (again, with the quantity of abatement undertaken in a period of time – not over time). If they do so at a constant rate, then total costs would be a quadratic function of the required reductions. It is not inconceivable that they could rise even faster.

The possibility of no-cost or low-cost reductions only makes the curve steeper in lowering its starting point (business-as-usual emissions). When near-term abatement reaches the point where premature replacement of existing capital stock is warranted, costs will turn rapidly higher.

2.2 Benefit curve: uncertain but flat

To elaborate the (long term) benefit curve of short term mitigating policies, that is, the damage cost curve associated with greenhouse gas emissions, one has to follow a number of successive steps and look at the links between them. These are the following:

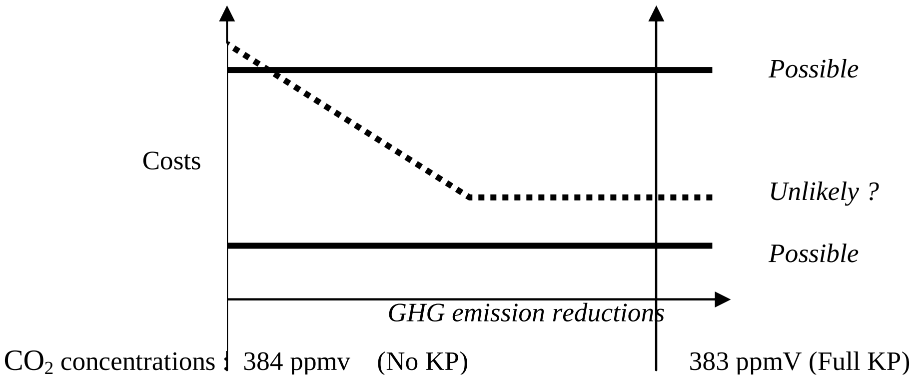
- *From emissions to concentrations.* Climate change is not a result of instant (or yearly) emissions. It is triggered by the accumulation of GHG in the atmosphere. Emissions in any single year represent a small fraction of the additional greenhouse gases (especially CO_2) accumulated since the beginning of industrialisation. Climate change is not a flow issue, but a stock issue – this is the main reason that flattens the damage cost curve with respect to marginal emission reduction.
- *From concentrations to radiative forcing.* Radiative forcing is a logarithmic function of CO_2 concentrations in the range considered, while methane and nitrous oxide show a square-root dependence of the forcing on their respective concentrations. Hence, each additional tonne – or billion tonnes – of either gas creates a lower temperature change than the previous one (IPCC, 1994).
- *From radiative forcing to global mean temperature change.* While the relation between radiative forcing and temperature change varies from one model to another, within each model has it found to be remarkably constant for a wide range of radiative perturbations. Estimates of the Earth's "climate sensitivity" (equilibrium temperature change associated with a doubling of pre-industrial CO_2 concentration) remained in the range 1.5°C to 4.5°C since the First Assessment Report of the IPCC, and this range is unlikely to be narrowed soon (Kerr, 2004).
- *From global mean temperature change to a variety of climate changes, and from climate changes to damages.* Local and regional climatic changes are uncertain. Still, climate change damages are very likely to increase with temperature change. The possibility of some climate change benefits associated with low concentration levels increases the steepness of the damage curve in lowering its starting point.

- *From damage to damage costs.* Associated costs are uncertain, especially those arising from the possible destruction of non-market environmental assets. Differing views about valuing such assets, and discounting future damage costs, contribute to make cost benefit analyses highly speculative.

In sum, as the IPCC has put it, *"there is a wide band of uncertainty in the amount of warming that would result from any stabilised greenhouse gas concentration"* (Watson, 2001). The uncertainty on environmental costs is even greater. But, mainly because climate change is driven by the cumulative change in GHG concentrations, not instantaneous emissions, marginal damage cost, how important they may be in absolute terms, are likely to be roughly constant over narrow ranges of GHG concentrations corresponding to relatively short periods of climate mitigation efforts.

To give an example, let us figure out on Figure 3 below some possible benefit curves of the Kyoto Protocol over 2008-2012. The Kyoto Protocol was (in the context of 1998) likely to avoid the emission of 4 to 6 billion tonnes of CO_2-Equivalent from a total of 140 billion tonnes to be emitted from 1990 and 2012 worldwide. As a result, CO_2 concentrations in 2012 would be about 383 parts per million in volume (ppmV), against around 384 ppmV with uncontrolled emissions, according to IPCC's former Chairman Bert Bolin (1998). A more aggressive and comprehensive agreement could perhaps reduce forthcoming concentration by up to 5 or even 10 ppmV over an equal period of time (15 years). Most likely, marginal benefits are constant within such short intervals of concentrations.

Figure 3: Marginal benefit curves under the Kyoto Protocol in 2012



Arguably, this assessment can hardly take into account the intangible long term benefits of taking a first step, from political dynamics to technology development, which could likely facilitate the following steps. These benefits, however, more likely depend from the breadth and the ambition of the policy followed, than from its capacity to deliver very precise emission outcomes.

Let us summarise. Climate change mitigation policy costs and benefits are both uncertain, but policy benefits are roughly constant over time frames when policy costs could rise steeply with abatement. In such cases, economic analysis points to taxes or hybrid instruments as the preferred options to control pollution. An intuition of this result would be as follows: The – very theoretical – elimination of emissions in a year or a decade would be tremendously costly to a global economy that still takes about 80% of its primary energy supply from fossil fuels. Whatever the benefits of mitigating climate change, there is likely to be a point in abatement beyond which incremental abatement costs more than it is worth.

What would, however, modify the slope of this curve (and possibly reverse the policy conclusions) would be an abrupt change in the response of the climate system at some point in the "chain" linking growing CO_2 concentrations with marginal damage. This possibility will be further discussed below in section 3.

2.3 Modelling exercises

All modelling exercises suggest that price or hybrid instruments, or indexed targets, are more efficient than (fixed) quantity instruments to address climate change. This section presents their main features and outcomes, and discusses their robustness.

Pizer (2002) built an integrated climate-economy model, based on Nordhaus' DICE model (Nordhaus, 1994), capable of simulating thousands of uncertain states of nature. He suggests that expected welfare gains with taxes would be five times more than with permits: *"In the year 2010 only, the optimal price policy would yield expected social benefits (as compared to uncontrolled emissions) of $2.5 billion in net present value versus $300 million only for the optimal quantity policy. In the long run, optimal tax policy would yield $337 billion against $69 billion for the optimal permit policy."*

Pizer also considers a hybrid instrument of an emission cap and a price cap, or "trigger price" (no price floor). It turns out to be only slightly more efficient than a tax policy. However, it does so while preserving the "political appeal" of permits, which Pizer summarises as *"the ability to flexibly distribute the rents associated with emission rights"*. This may include the possibility to agree on the distribution of mitigation costs between countries through the differentiation of assigned amounts, as well as the possibility for governments to soften the transition with the domestic allocation process.

Given the flatness of the benefit curve, the price cap would be set up close to the best guess marginal cost attached to the target (implicitly equal to the best guess marginal environmental damage). Therefore, and especially if the target is further tightened, the price cap is rather likely to intervene, and the hybrid will turn in a price policy. However, Pizer also shows that hybrid policies based on an aggressive target and a high price cap, which he believes are "less optimal", lead to much better welfare outcomes (greater net benefits or lower net losses) than the same target with no price cap.

Pizer's (2002) quantitative results may be considered dependent on various questionable assumptions of his model. These include assumptions about unabated emission trends, discounting, climate sensitivity, and damage valuation. The policy he finds "optimal" would never lead to achieving GHG stabilisation. On the basis of comparable models, Hoel and Karp (2001; 2002) and Newell and Pizer (2003) have conducted extensive sensitivity analysis, in particular to test the robustness of the policy conclusions with significantly higher damage estimates. They found that the preference for taxes or hybrids would only be reversed with damage estimates at least one hundred times higher than their assumptions.

3. Longer term analysis

The above discussion indicates a theoretical preference for price or hybrid instruments over quantity instruments over a short period. But how does this fit the long term dimension of climate change? Is this preference reversed in face of possible climate surprises – sudden climatic changes that would make the damage curve steeper? Is it compatible with achieving the ultimate objective of the UN Convention on climate change? This section attempts at answering these important questions.

3.1 The longer term perspective

Climate policies aim at stabilising GHG concentrations in the longer term. Stabilising CO_2 concentration eventually requires near elimination of net emissions – a very sharp reduction of gross emissions. The inherent uncertainty associated with price instruments seems contradictory with the stabilisation concept. The question is therefore whether an analysis based on the possibility of rapidly rising abatement cost and relatively constant marginal climate benefits in the near term remains valid when looking at the long term dimension of the climate change issue.

Near elimination of emissions would be best ensured with quantity instruments. Should one thus consider setting long term quotas and full "time flexibility" in achieving them? Current uncertainties may make such decision difficult. Moreover, there is always a risk of governments and other agents leaving it to their successors to implement mitigation, especially if compliance is not enforced in the interim (Philibert 2005b, p.17).Victor and Coben (2005) provide a strong warning: *"In practice that approach might entail allocation of credits for allowable emissions to all emitters in the world for the next century (ideally longer) and then let them trade over time and space to find the best solution. Certain that the limit is binding, innovators will focus their minds and capital on new low-carbon and zero-carbon energy systems. The problem with this solution is that it is neither politically possible, nor desirable, to establish a credible policy for a century. Even within long-standing nation states, governments and policy priorities change."*

Thus, the long term climate mitigation strategy is likely to remain based on relatively short term periods – the first commitment period of the Kyoto Protocol will last 5 years, and 15 years will have passed between the initial negotiation on targets in 1997 and the end of the commitment period. Thus, in the range of any credible policy interval, marginal benefit will likely be roughly constant. However, in the longer term it may not, as GHG concentrations would reach higher levels. Marginal climate damages should increase over time if emissions remain unabated.

Conversely, in a world that gives a price to carbon emission reductions, new technologies will be invented and brought to the marketplace, benefiting from learning-by-doing processes and hopefully from some public R&D support. These technologies apt to provide the same amount of goods and services with less carbon emissions will range from more efficient end-use technologies to carbon-free energy sources such as renewables, nuclear power and CO_2 capture and storage. Thus, while abatement costs increase sharply with the level of GHG reductions required in the near term, they would progressively decrease over time.

Newell and Pizer (2003) found that a likely cost decline over time, and a likely benefit rise, would actually reverse the preference – as marginal costs fall, the cost savings under price policies become less important; as marginal benefits rise, the stock certainty assured by quantity policies becomes more important. Therefore, an optimal strategy with only pure instruments could consist in using price instruments first and switching later for quantity instruments.

In both periods, however, hybrid instruments would remain more efficient than either pure instrument. Moreover, they can be twisted in the direction of either pure instrument – a price cap close enough from the best guess abatement cost would resemble a tax, a price cap much higher would likely ensure the domination of the quota. A hybrid framework could thus evolve from a quasi tax to a quasi pure quota, if Parties manage their targets and the price cap level appropriately over time. This is what would happen if one follows the suggestion made by Jaccard (2006, p. 309): the price cap *"should be scheduled to climb over time in conjunction with a reduction in the cap so that environmental effectiveness of the policy increases at a pace consistent with the time needed for innovation and commercialization of new technologies, and the natural turnover rate of equipment, buildings and infrastructures."*

Finally, one may wonder how the use of price caps would interfere with the technology developments that are necessary, in particular for the longer term. Indeed, from an investor point of view, the mere presence of a price cap reduces the expected benefits of investing in carbon abatement and investing in climate-friendly technology research and development. However, this reduction would be partially offset if the price cap facilitates tightening the target.

Moreover, the price cap could arguably reduce price volatility, which tends to deter investments, as the history of oil prices has amply demonstrated (Hasset and Metcalf, 1993). How these two opposite effects would combine is itself uncertain. Finally, the need to develop some technologies currently in their infancy may justify that the emission abatements they can provide today be bought at a higher price than average. Helping early market deployment will speed cost reductions thanks to learning-by-doing processes, and thus reduce the cost of future emission reductions. However, this can hardly be done through a general, indiscriminate emissions trading regime. It seems more appropriate to provide the necessary incentives to new technologies through specific instruments (Sanden and Azar, 2005).

Naturally, the most important effect of near-term policy is its influence on future emissions and mitigation costs, not current emissions. The direct impact of near term action on CO_2 concentration will be small. Its true value is to create a carbon price that will drive technical and other changes with more important long-term impacts on CO_2 concentrations. However, as Pizer (2002) pointed out, *"such an effect is arguably more dependent on the aggressiveness of mitigation policy than the choice of policy instrument."*

3.2 Climate surprises

The literature suggests various possible non-linear responses to the climate forcing of greenhouse gases: "runaway" warming, abrupt changes in the oceanic circulation patterns and notably a slow-down or even disruption of the North-Atlantic thermohaline circulation, abrupt melting of West-Antarctic and Greenland ice sheets and others (see, e.g., Schellnhuber et al. 2006).

The perspective of climate surprises must be fully taken into account. It has inspired approaches such as the "tolerable window" and "safe-landing", which seek to evaluate what rate of temperature and what maximum temperature could prevent such surprises. They then proceed to assess what emission paths and what ultimate concentration levels could keep actual temperature change below this rate – and average temperature below this identified maximum.

However, thresholds in concentration that might trigger such big, perhaps even catastrophic changes, are unknown. Although clearly the probability of a surprise increases with concentration rise, the uncertainty on possible thresholds tends to smooth the expected damage function. As a result, the possibility of "nasty surprises" does not necessarily reverse the preference for price or hybrid instruments in the above analytical framework – although it would be an obvious justification for a more ambitious policy.

In other words, let us suppose that the possibility of non-linear climate change convince us to adopt a firm, global quota. We might be lucky, and set it right below the threshold in concentrations. We may also set the level far below the actual threshold, and in this case, we might have had too high mitigation costs. We may finally set our target above the unknown threshold and in this case our abatement efforts would not prevent the catastrophic damage. The possibility of a threshold certainly warrants an ambitious policy, but unknown thresholds hardly justify the added cost of a certain emission levels.

Pizer (2002) conducted a sensitivity analysis on the exponent of the damage cost function, which links the economic cost of climate change to temperature change. He found that the preference for price instruments holds until the non-linearity becomes quite large, making costs a function of the seventh power of the temperature change.

However, this risk would justify short-term quantity instruments on the same economic grounds that would also justify a very stringent policy. For example, Newell and Pizer (2003) estimated that only a 40% or more short-term reduction in global carbon dioxide emissions could reverse the preference for price policy. According to this analysis, a quantity instrument is only justified if we seek to achieve a near immediate 40% or more reduction in emissions from business-as-usual trends, as has been the case with ozone-depleting substances in the Montreal Protocol.

For less drastic policies, price or hybrid instruments would fare better, because in reducing expected abatement costs they could facilitate the adoption and implementation of more ambitious targets. This is what the risk of nasty surprises indeed justifies, and the best way to reduce their probability of occurrence.

3.3 Achieving the UNFCCC ultimate objective

The Convention and the Parties have not determined thus far what concentration level would *"prevent dangerous anthropogenic interference with the climate system"*, as required by the ultimate objective of the Convention. Nor have they defined what time-frame for achieving that level would *"allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".*

A growing body of literature examines the possibility and usefulness of setting long term targets. Almost all analysts conclude that soft or indicative targets would help focus long term expectations but should not be translated into firm and definitive commitments, given the range of the uncertainties – and diverging views. As Pershing and Tudela (2003) have put it, *"even if consensus on what constitutes "dangerous" could be reached, to be of real utility, an impacts target would have to be translated back through the other stages of the climate cycle to human activities. But the link between stabilised concentrations and temperature increases is itself uncertain. (…) A concentration target effectively sets an upper bound on allowable cumulative emissions over a given period. But it leaves open the question of the most feasible or cost-effective emission trajectories consistent with that target. "*

Corfee Morlot et al. (2005) see the process of discussing long term goals as more fruitful than agreeing to a precise number: *"The exact level of any long-term goals may be less important to negotiations than discussion of such goals and their implications for regional impacts. Any convergence towards agreement on an upper limit in the long term would indicate upper bounds for nearer-term emissions. The aim of related policy decisions would be to constrain emission pathways such that they leave open the possibility to achieve loosely agreed long-term goals or 'soft targets'."*

According to the IPCC (Metz et al., 2001), *"climate change decision-making is essentially a sequential process under general uncertainty."* This means in particular that *"decisions about near-term climate policies are in the process of being made while the concentration stabilisation target is still being debated. The literature suggests a step-by-step resolution aimed at stabilising greenhouse gas concentrations. This will also involve balancing the risks of either insufficient or excessive action. The relevant question is not 'what is the best course for the next 100 years', but rather 'what is the best course for the near term given the expected long-term climate change and accompanying uncertainties'".*

The use of hybrid instrument instead of fixed targets may help get an agreement on sufficiently ambitious near term targets compatible with "leaving open" the possibility to achieve *"loosely agreed long-term goals"*, while an agreement on any firm stabilisation level is unlikely. It makes sense to keep options open as long as the costs entailed are not "excessive", i.e., higher than the marginal benefit implicitly or explicitly assumed by the long term stabilisation level considered. Thus, an ambitious near term aim should be relaxed if marginal abatement costs turn out to be higher than anticipated. However, as the IEA has put it (2005), *"deviations from targets set in this context must best be compared not only to the targets themselves, but also to the proposed fixed and binding commitments".*

The need to regularly adjust the policy to new knowledge about the climate and thus, environmental benefits, and the abatement costs, is widely recognised. Adjustments, however, seem to follow the slow pace of international negotiations. The presence of a price cap could lead to spontaneous adjustments of the level of action when and if the international permit price reaches the pre-agreed level. Jacoby and Ellerman (2004) warn that *"the application of the safety valve proposal will naturally raise objections concerning how these inconsistent components are to be harmonised"*. However, one may see it as a fundamental and long-lasting way of addressing the uncertainties surrounding all aspects of the climate change problem. Its use would allow progressive and partial resolution of the cost-benefit analysis that uncertainties on both costs and benefits prevent from undertaking today.

4. The Price cap in the international context

Implementing hybrid instrument in multilateral environmental agreement raises various difficulties. It is not, however, totally unprecedented. Victor and Coben (2005), for example, see the provisions under the Montreal Protocol that allow each country to define every year some "essential uses" of ozone depleting substances as a true price cap or "safety valve". Still, many practical questions have been raised about a more straightforward implementation of the concept in future agreements about climate change.

Philibert (2005a) alluded to the appropriate level of implementation, international or domestic, the possible use of the money raised, if any, and the link with compliance regimes. Still, the question of the price cap level is a critical one, which requires more attention. Agreeing on a single price cap would be "a nightmare" for some (Mueller et al., 2002), for countries have different willingness-to-pay for climate mitigation, and different views on likely benefits and costs of climate policies. However, differentiating the commitments through allocation, as with fixed targets, would help meet the willingness-to-pay of different countries.

Although a unique price would make any future international trading system more efficient, Philibert (2005b) shows that under some safeguard clauses trading between zones with different price cap levels remains possible, and envisages as an example *"a very low price-cap for low income developing countries*", noting that a price of zero would turn any commitment into a non-binding target, *"a low price cap for the advanced developing countries and most economies in transition"*, and *"a higher price cap for other industrialised countries"*. The IEA (2005) recalls that a country with a price cap would not be obliged to use it, even if the cost of domestic reduction reaches its level. Therefore, *"a country with a low price cap may fulfil its commitment at a marginal cost above this cap, to allow profitable allowance sales when the international carbon price reaches a higher level."* Benefits from units traded could pay for the abatement that the country needs in order to be in compliance.

In theory, the determination of a price cap would proceed in three stages: agreeing on targets in the absence of a price cap; setting price cap in the upper range of forecasted costs for theses targets; tightening the initial targets (IEA, 2005). The initial price cap level might now appear in the lower, not higher, range of cost expectations, thus turning the system closer to a price instrument than to a quantity instrument. However, as Aldy et al. (2001) had put it, *"The safety valve is not intended to set an inefficiently low carbon price over time. Indeed, the safety valve may allow a higher price of carbon than would otherwise be the case, because it provides assurance that the costs will not exceed that level"*.

This optimal process can be conceived if a single decision-maker were in charge. Whether the international community could follow such a process remains to be seen. *"A price cap falling far below the level of forecasted costs would act as a carbon tax, entirely cancelling any ambition in the targets"* (IEA, 2005). The fear that a price cap would be set "too low" for pleasing the countries the most adverse to the economic risks of climate mitigation looms large within environmentalist NGOs or environment administrations. Indeed, while the theory suggests that more flexible options could be associated with more ambitious target-setting, in the real world the same aversion to the economic risks of climate mitigation may lead a government to simultaneously prefer relatively lenient targets and flexible options. However, one may wonder why the same countries would adopt more ambitious targets without any price capping mechanism than with it, despite the higher associated expected costs.

Moreover, under the common understanding that the price cap is to be set in the upper range of cost expectations associated to a given quantified objective, the price cap may help narrow the range of cost expectations publicly put forward by various interest groups – or various governments. Those who tend today to highlight high cost expectations may then be prevented to do so, for high cost expectations could lead to high-level price caps – while they would likely prefer price caps set at a level as low as possible. Conversely, those who tend today to lower cost expectations to facilitate the adoption of ambitious targets, might also think twice, for these low cost expectations could lead to low-level price caps – exactly what they fear the most.

Finally, when possible damage cannot be given probabilities (“deep uncertainty”), there is no “best guess” on what the environmental benefits might be. The economic analysis cannot make any strong recommendation on setting emission limits. In having two parameters to set instead of only one, governments may feel that hybrid instruments offer them increased flexibility to accommodate different views about the likeliness of various possible environmental consequences.

5. Conclusion and future work

This paper has reviewed the literature on instrument choice to reduce pollution when abatement costs are uncertain and its application to climate change. The literature suggests that because climate change is a long term issue driven by the slow accumulation of greenhouse gases in the atmosphere, abatement costs grow faster than benefits in short periods when the level of abatement increases. In such cases, taxes and, *a fortiori*, hybrid instruments – e.g. combining emission quotas with price caps – would be more efficient than fixed emission limits.

Introducing a price cap into an emissions trading system would reduce expected costs more than expected benefits. It would thus make possible to define more ambitious emission quotas, entailing lower expected costs while bringing higher expected environmental benefits. The certainty on near term emission levels offered by fixed targets is of little economic value, compared to the possible short and long term environmental gains of more ambitious policies.

The risk of climate surprises, and the need to eventually stabilise greenhouse gas concentrations justify ambitious policies that a price cap may favour, but add little to the value of certainty on emission levels. This is because thresholds in concentrations that might drive climate surprises are unknown, as is the desirable level at which GHG concentrations should eventually be stabilised.

Several questions about implementation of price caps remain to be addressed in detail. These include in particular fuller consideration of the implications of implementing price caps at “international” versus “domestic” levels, as well as the possible uses of price cap revenues, if any. They could be the focus of some future work. Another possible area for future work could be an assessment based on an analytical framework similar to the one used here of the economic efficiency of indexed targets. Finally, it could be useful to compare the efficiency of two strategies for achieving stabilisation, one with a firm emissions objective and the other with a more ambitious emissions objective and a price cap.

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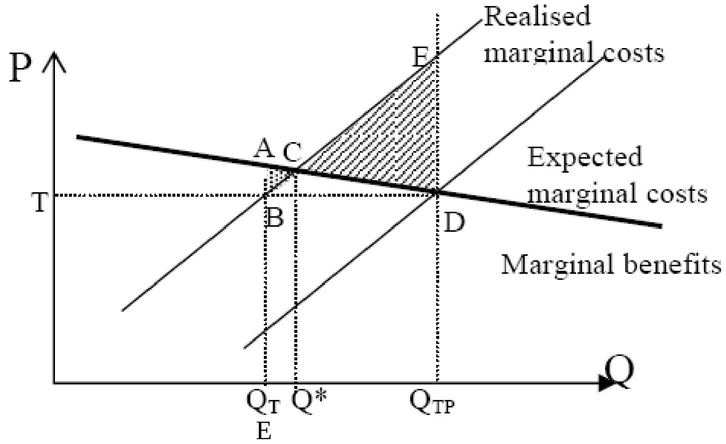
Appendix

Prices vs Quantities: a graphic representation

These figures illustrate the relative losses of welfare (by comparison to the optimum) that may arise from different policy choices in the context of cost uncertainty. The first two figures show that when the marginal cost curve is steeper than the marginal benefit curve, the choice of a price instrument leads to lower welfare losses. The next two figures show that when the marginal benefit curve is steeper than the marginal cost curve, the choice of a quantity instrument leads to lower welfare losses. Both results hold whether the actual costs turn out to be higher or lower than anticipated.

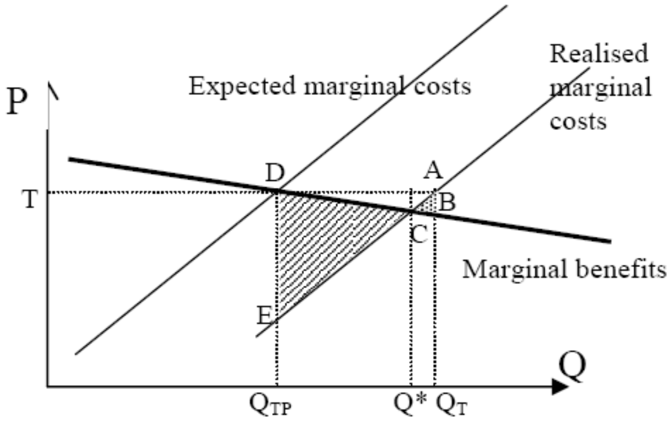
Figure 4: **Flat benefits, higher-than-expected costs**



T is the level of a tax that would equalise expected marginal costs and benefits. Q_{TP} is the equivalent quantity of tradable permits. Ex post efficient amount of emission reduction is Q. In this case, costs have turned out higher than anticipated.*

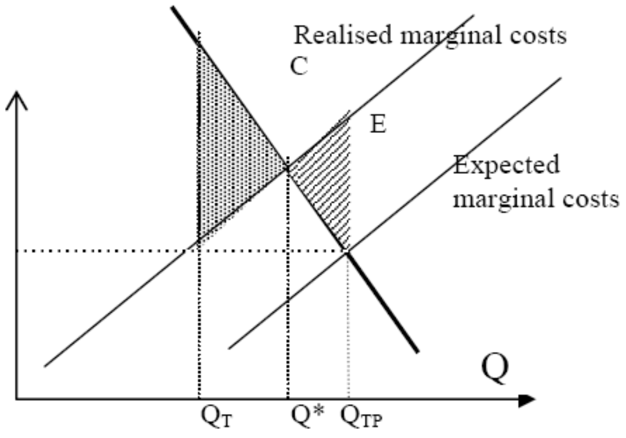
Q_T is the quantity delivered by a tax after cost uncertainty is resolved. The loss associated with the tax, represented by the triangle ABC, is smaller than that of the permit programme, figured by the triangle CDE. The quantity delivered by the tax is closer to the optimum than the quantity delivered by the tradable permit scheme.

Figure 5: **Flat benefits, lower-than-expected costs**



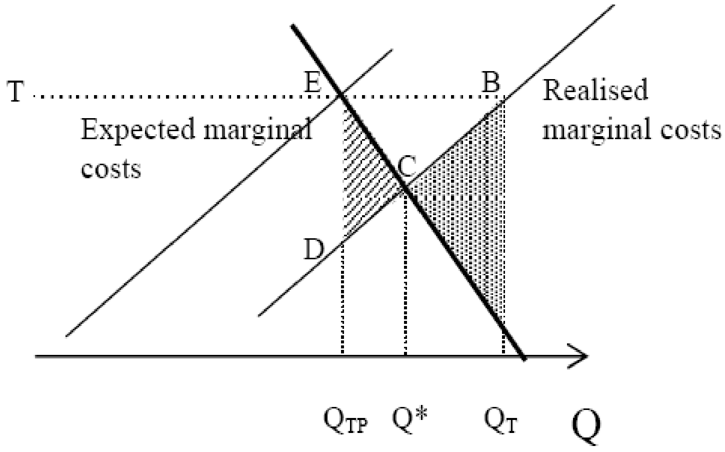
Now the abatement costs turn out to be lower than expected. However, the welfare loss associated with the tax, ABC, is still lower than that of the permit programme, CDE. The quantity delivered by the tax is again closer to the optimum than that delivered by the equivalent (under best guess) quantitative instrument.

Figure 6: **Steep benefits, higher-than-expected costs**



Now the benefit curve is the steepest one – meaning that, absent any control policy, the damage would increase sharply. Costs turn out to be higher than expected. The welfare loss associated with the tax, ABC, is larger than that associated with the quantitative instrument, CDE. Q_T *is now closer to Q* than* Q_T.

Figure 7: **Steep benefits, lower-than-expected costs**



In this last case, abatement costs turn out to be lower than expected. The welfare loss associated with the tax, ABC, is again larger than that associated with the permit system. The latter delivers a quantity closer to the optimum than a price policy. As is the previous case, a quantity instrument is to be preferred. The instrument choice depends on the relative slopes of cost and benefits.