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Certainty versus Ambition

Economic Efficiency in Mitigating Climate Change

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The views expressed in this Working Paper are those of the author and do not necessarily represent the views or policy of the International Energy Agency or of its individual Member countries. Earlier versions of this Working Paper have benefited from discussions within the Annex I Expert Group to the UNFCCC. As this paper is a Work in Progress, designed to elicit comments and further debate, comments are welcome, directed to the author at cedric.philibert@iea.org. This work has been made possible thanks to a grant from the French government through ADEME, the French Environment and Energy Efficiency Agency

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CERTAINTY VERSUS AMBITION

Economic Efficiency in Mitigating Climate Change

Cédric Philibert

Abstract

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 does not attempt to perform a cost benefit analysis of the climate change problem. Instead, it reviews the economic literature relative to the choice of the economic instruments that could be used to mitigate climate change in context of uncertainty. 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 short periods of time, the marginal benefit is more or less constant. On these grounds, flexible instruments would fare better than fixed 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.

Flexible instruments such as hybrids combining quantity objectives and price caps or quantity objectives indexed on some economic variable may be more attractive than fixed quotas to governments wary of possible costs beyond what they feel acceptable. Therefore, flexible instruments may help engage a broader set of countries into a common, cost-effective framework for mitigating climate change.

Moreover, price caps or indexed targets would lower the expected costs of targets. Their use could thus facilitate the adoption of more ambitious policies than without it, resulting in higher expected environmental benefits. In other words, while the certainty of achieving at least some precise levels of emissions would decrease, the probability of bettering these levels would significantly increase.

Cost-effectiveness in mitigating climate change requires “where” and “when” flexibility. Efforts need to be allocated in an acceptable manner – some “who” flexibility. Economic efficiency, or the capacity to make abatement costs match the benefits as close as possible, requires on top of cost-effectiveness a continuous adjustment of the objectives to the actual costs. Flexible instruments should provide for “where to” flexibility.

Agreeing and implementing at an international level quotas and price caps, or quotas and index formulas, may not be easy, however, and the international negotiation may not necessarily lead to optimal outcomes.

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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). In case such quantitative commitments are to be retained – at least by some countries – in future international framework to mitigate climate change, it is useful to analyse the implications of the various options for the economy and the environment, so as to enlighten the choices to be made.

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, often also called "safety valves".

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 broader set of countries.

It has also been argued that these more flexible options could facilitate the adoption of relatively more ambitious targets than under fixed 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 – with respect to both the breadth and the depth of participation.

This paper mainly focuses on price caps or, more generally, "hybrid instruments" made of emission limits, a price cap and a price floor, for they seem easier to apprehend analytically. There is a small but growing literature analysing the efficiency of indexed targets (Jotzo and Pezzey, 2006; 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; see also Jotzo, 2006). 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"*, but Jotzo and Pezzey offer conflicting results. There seems to be no straight comparison of indexed targets and price caps available in the literature yet.

Nevertheless, this paper assesses the value of using flexible options or price-capping mechanisms in general and does not prejudge on the relative merits or the practicability of each of them – safety valves, indexed targets or others. As such, this paper does not focus on any particular group of countries, and may have implications for developed and developing countries alike.

The next section of the paper summarises the literature on economic instruments when pollution abatement costs are not known with certainty. The third section applies this analytical framework to climate change, looking at near term policies. The fourth 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 fifth section considers how flexible instruments could be negotiated and used in an international context. A sixth section spells out various dimensions of flexibility and briefly compare how various options for future climate action respond to these various dimensions of flexibility. A conclusion summarises the key points and suggests possible future work on related topics.

1. Quantity instruments versus price instruments

This paper does not attempt to perform a cost-benefit analysis of future action against climate change – a task that uncertainties on abatement costs and benefits (i.e. avoided climate damage) would make difficult. Instead, this paper provides a stylised analysis of instrument choice under uncertainty. The uncertainties that prevent an economic analysis to capture all the dimensions of the complex climate change issues in a few numbers, and the economists to do firm recommendations to policymakers, are not ignored; on the contrary they figure at the core of this analysis.

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*

Price and quantity instruments are no longer equivalent 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:

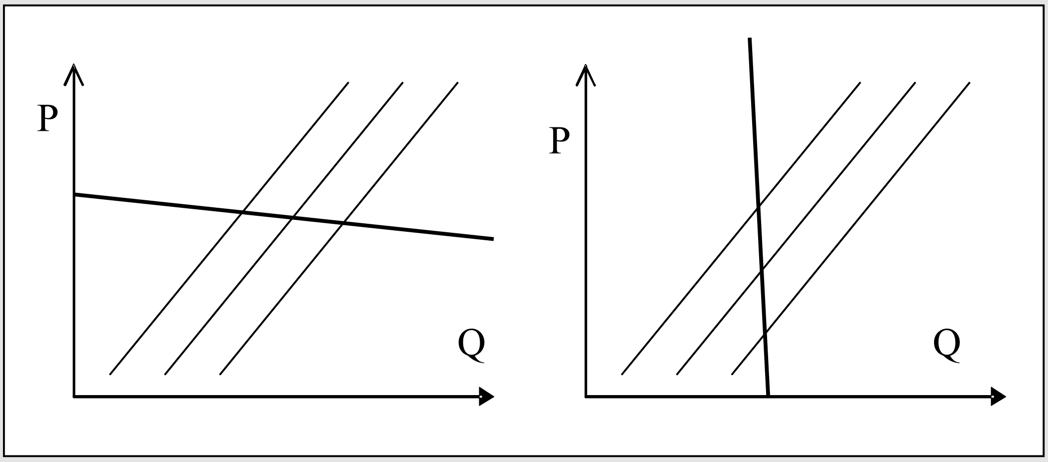
- Suppose the marginal benefit curve of the environmental policy is steeper than the marginal cost curve. The damage rapidly increases with the level of pollution. Then it is worth getting full certainty on the level of pollution, rather than risk suffering too much environmental damage. Quotas should 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 38.

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.

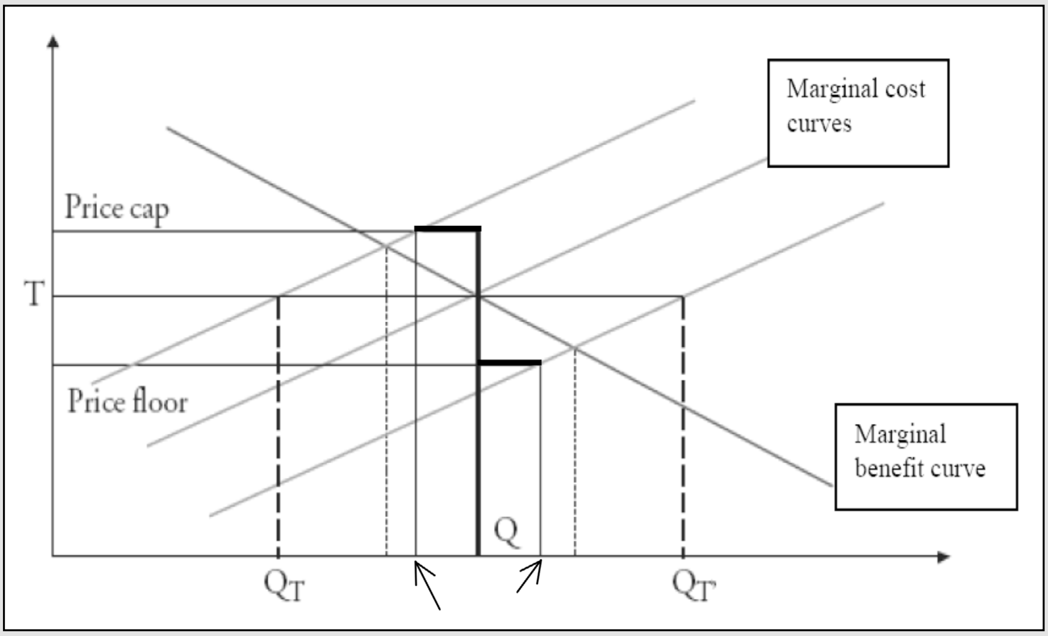
Moreover, uncertainty on the environmental damage cost, especially when it seems "deep" enough – when there is no scientific agreement on the probabilities of distribution of the various possible outcomes – may increase the difficulty of agreeing on quotas. Some instruments may have a greater ability 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.

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). They are also closer to the optimal pollution levels than the quantities Q_T or $Q_{T'}$ that the equivalent tax T would achieve.

Cournède and Gastaldo (2002) have further explored hybrid instruments. In their analytical framework, which supposes that benefits can be assigned probable values, 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 (again, in a framework with benefit values with associated probability functions).

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).

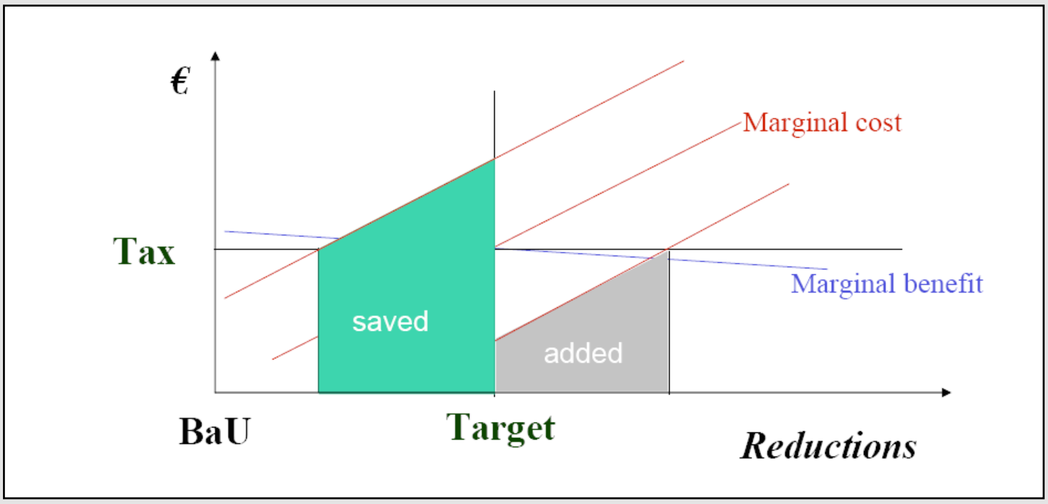
A tax entails lower expected costs than the equivalent quota, because less abatement is undertaken when costs are high (above the tax), and more when costs are low. But – taxes also reduce expected benefits. This arises from the decreasing marginal benefits when abatement increases – the possible environmental 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. As illustrate figures 3 and 4, 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 taxes clearly are 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.

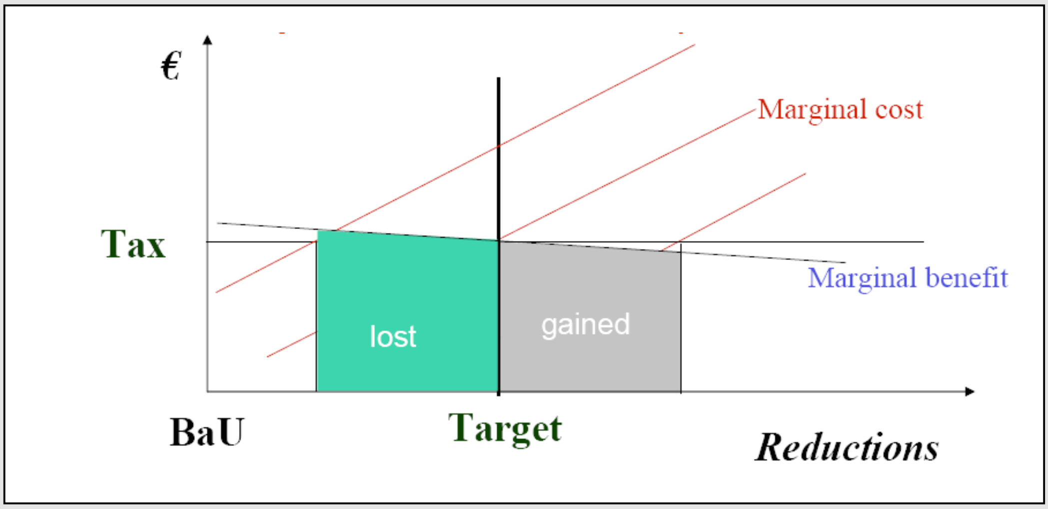
One step further would be to adopt an even higher tax that would entail the same expected costs than the "equivalent" quota. This higher tax offers significantly higher expected benefits than the equivalent quota.

Figure 3. Significantly lower expected costs



When abatement cost rise faster than the benefits, using a tax instead of a target reduces the expected costs. "Added" costs due to additional reduction when costs turn lower than forecasted would cost less than the costs "saved" from reductions not achieved in the opposite case.

Figure 4. Slightly lower expected benefits



When abatement cost rise faster than the benefits, using a tax instead of a target may slightly reduce the expected benefits. Benefits "gained" thanks to additional reduction when costs turn lower than forecasted may bring slightly lower benefits than the benefits "lost" in the opposite case.

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.

This would also apply to a hybrid instrument. In reducing expected costs a price cap could allow choosing a more ambitious quantitative target providing higher expected benefits at lower expected costs. While it has been argued that a tightening of the target would not be necessary or justified if there is a price floor as well as a price cap (Cournède and Gastaldo 2002), this argument may not hold in case of "deep uncertainty" on climate change damage, i.e. if there is no probability function and no best-guess on the marginal damage.

In such case the economic analysis cannot pretend make a recommendation on the appropriate level of action. However, as long as the behaviour of the marginal benefit and cost schedules can be postulated with some degree of plausibility, the economic theory can still provide useful insights on the choice of instruments, as will be seen now in the case of climate change.

Moving from textbook theory to real world policy decisions, one must recognise the influence of many factors relating in particular to national circumstances. This does not mean there is no trade-off between the ambition of the environmental policy and the certain (or not) nature of what it delivers. Quite to the contrary, as notes one commentator to a Cap-and-Trade Workshop held by California's "Climate Action Team" (Johnson, 2005), *"considerations of cost acceptability generally take precedence over environmental goals in setting emissions caps, and* *without a safety valve, the only way to assure cost acceptability is to set the cap high enough that auction bids and trading prices will not exceed acceptable limits under the most pessimistic cost assumptions. (…) With a safety valve, the cap level need not be so extremely biased toward cost conservatism, because compliance costs are directly controlled. Hence the cap could be set according to environmental requirements. Of course, there is no guarantee that the emissions cap level will actually be attained, but an alternative policy without cost controls would not perform any better unless its costs exceed the safety valve's price ceiling."*

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 about greenhouse gas emissions control, *"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, two years after the adoption of the Kyoto Protocl, the marginal cost of achieving its from less than $20 to more than $200 per tonne of carbon (Weyant and Hill, 1999). As the US Senator Bingaman (2005) explains, *"Some assert that technology will develop quickly once a market-signal is in place, enabling low-cost compliance. Others take a more pessimistic view of technology progress and assert that any mandatory reduction regime will have devastating economic impacts. As this is a disagreement about different projections of the future, no side can ever 'win' this argument."*

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).

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.

Over the longer term, however, technological developments may reduce marginal abatement costs. This possibility, further discussed in section 3.1, is unlikely to significantly modify the steepness of the curve of the short term abatement costs, given the usually long lead time of technology developments, and therefore irrelevant for the choice of short term policy instruments.

2.2 *Benefit curve: uncertain but flat*

To elaborate the (long term) benefit curve of short term mitigating policies one must first consider the damage cost curve associated with greenhouse gas emissions. This follows a number of successive steps that 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. In others words, although the marginal damage curve of climate change is very likely to increase over time when GHG concentrations increase, in any short term (e.g. decadal) period of time the marginal damage cost is likely to be roughly constant. This is even truer with respect to the marginal damage benefit of short term mitigating policies, as these are unlikely to bring in considerable change in the level of GHG concentration reached at the end of each policy period (for any given starting level that results from past policies).

A quantitative illustration of the "stock" nature of the problem may help. The current atmospheric content of CO_2 is about 2950 billion tonnes, or 380 parts per million in volume (ppmV). Yearly man-made emissions are estimated at about 30 billion tonnes, or 1.1 % of the atmospheric stock. The yearly rate of increase in atmospheric concentrations is about half that due to the uptake of CO_2 by the ocean and terrestrial ecosystems (IPCC, 2001), or about 2.1 ppmV. An effort to reduce global emissions by 20% would thus bring about reductions of 6 billion tonnes, and slow the increase in concentrations by roughly 3 billion tonnes, or about 0.4 ppmV per year. Over ten years the difference would be 4 ppmV, over fifteen 6 ppmV.

This is not to dismiss the value of such (hypothetical) effort. The marginal benefit of another avoided tonne of CO_2 might be important – we do not know its value for sure. It seems unlikely, however, that the benefit of abatement had significantly different marginal values around, say, 411 ppm and around 417 ppm, unless there were precisely a trigger for non-linear changes between these numbers (hypothesis considered in more depth in section 3 below). The marginal benefit (whatever it is) of credible climate change mitigation policies might thus be thought roughly constant over relatively short (here 15 years) periods.

Arguably, one need to 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 greater 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 with 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. However, Pizer also notes that hybrid policies he finds "sub-optimal" – with a carbon price set too high" – would *"offer dramatic efficiency improvements over otherwise standard quantity controls"* – turning, in one example he provides, losses in trillion dollars into benefits in billions.

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 relatively short periods. 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*

The ultimate objective of the United Nations Framework Convention on Climate Change is to stabilise GHG concentrations – at a level and within a timeframe that have been left undecided. 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 fixed quantity instruments. Should one thus consider setting very long term quotas and full "time flexibility" in achieving them? This option presents two difficulties. First, 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."*

Second, very long commitment periods would need to take premature decisions on ultimate long term concentration levels – notwithstanding the difficulties of a realistic assessment of benefits and costs. Extending "time flexibility" may have the paradoxical but undesirable effect of reducing the flexibility to adjust the long term objectives to the reality of abatement costs and to the learning from climate sciences.

Thus, the long term climate mitigation strategy is likely to remain based on relatively short term periods – although possibly longer than to date. However, if the first commitment period of the Kyoto Protocol is set to last 5 years, 15 years will have passed between the initial negotiation on targets in 1997 and the end of the commitment period, and this time span is more relevant than the mere length of commitment periods. If the international community follows the road of quantitative commitments in the future, it remain to be seen if it wants to extend much beyond 15 years the time lag between the adoption and the achievement of future commitments. Thus, in the range of credible policy intervals, marginal benefit will likely remain roughly constant. In the longer term it may not, however, as GHG concentrations would reach higher levels; marginal climate damages would 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 from R&D efforts. 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 could progressively decrease over time.

The exact timing of this cost reduction remains uncertain, however. Higher oil and gas prices reflecting tighter balance between supply and demand may restrict the growth of energy demand, but also drive substitution of coal and non-conventional oil to conventional oil and gas resources, with higher life-cycle emissions. Thus, the progressive exhaustion of the less carbon-intensive fossil fuels – natural gas and conventional oil – may counteract the cost reductions arising from technological development. Surely in the very long term, when all fossil fuels become exhausted, and whatever the cost of alternative energy sources, carbon abatement will come for free, but unless carbon dioxide capture and storage has taken place on a very large scale CO_2 concentrations would at this time greatly exceed 1000 ppmV and approach 2000 ppmV (IEA 2002, p.44).

Let us nevertheless assume that technology development will dominate over oil and gas exhaustion and reduce CO_2 abatement costs in the coming decades, while damage costs would increase. 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."* Similarly, indexed targets could be made very close to fixed targets, or to full "intensity targets" (where the amount of allowed emissions is directly proportionate to the GDP), or anywhere in between, as demonstrated by Ellerman and Wing (2003).

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 or totally offset if the price cap facilitates tightening the target – arguably the target could be tightened up to the point where it would entail the same expected costs, though with much higher expected benefits. A similar reasoning might be conducted, to some extent, with respect to indexed targets.

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."* By making the climate policy more robust and protected against price spikes, flexible options and price-capping mechanisms, while alleviating the risk of costly premature capital stock retirement, would provide a greater insurance to investors that the policy will be conducted over a long time, thereby fully justifying investments in research and development.

3.2 *Climate surprises*

The scientific literature suggests various possible non-linear responses to the radiative forcing of greenhouse gases, or climate surprises: "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. Recent scientific studies have tended to identify critical temperature changes for some climate change impacts, such as: less than 1°C for coral bleaching, 1°C for the disintegration of Greenland ice sheet, 1-2°C for broad ecosystem impacts with limited adaptive capacity, 2°C for the disintegration of West Antarctic Ice Sheet, 3°C for the shutdown of thermohaline circulation. But only probability density functions can yet express the link between GHG concentration levels and these temperature changes (Schneider and Lane, 2006). It seems even less possible to identify any "tipping point" in the response of the climate system to small variations in emission trends over a decade or two, which have relatively little short term impact on the evolution of concentration levels. 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 fixed 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 or, to some extent, indexed targets would fare better, because in reducing expected abatement costs they could facilitate the adoption and implementation of relatively more ambitious targets. This is what the risk of nasty surprises indeed justifies, and a means 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 instruments or indexed targets 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, either directly and comprehensively through a price cap or indirectly and partially via indexed targets. 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, as well as to actual 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. Indexed targets would facilitate adjustments to unexpected variations in economic growth. 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. Complex instruments in the international context

Hybrid instruments are made of quantity objectives and price caps. Indexed targets necessitate quantity objectives and formulations for indexing them on economic variables. In any case they would be more complex instruments than simple fixed targets. Implementing complex instruments 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.

Considering price caps, 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, different views on likely benefits and costs of climate policies, and different national circumstances. However, differentiating the commitments through allocation, as with fixed targets, would help meet the willingness-to-pay of different countries. As notes Morgenstern (2004), "*In essence, this approach would shift the negotiations from the quantity targets to the appropriate level of the penalty, that is, to the maximum amount that a nation would have to pay to remain in compliance with the Protocol. As such, it might encourage ratification and acceptance of the terms of a quantity-based agreement by overcoming opposition based on the risk of unacceptably high costs."*

A unique price would make any future international trading system more efficient. Philibert (2005b) shows however that trading between zones with different price cap levels remains possible. Safeguard clauses must only ensure that a country where the price cap has been activated is not a net seller on the international markets. He 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".* Similarly, the targets adopted under the assumption that they are fixed and binding could be revised downward once formulas for indexation have been set up.

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.

There are reasons for this. The economic theory shows that more flexible options could be associated with more ambitious target-setting, for they would reduce the expected costs associated with a target. However, this reasoning rests on the assumption that governments act as rational agents seeking for the maximisation of net benefits, which may not be the case. More simply, different governments may have different perceptions of the environment and economic risks. In the real world the same aversion to the economic risks of climate mitigation may lead a government to simultaneously prefer flexible options and relatively lenient targets - or targets perceived as such by other governments or stakeholders.

On the other hand, one may wonder why the same governments would adopt more ambitious targets without any price capping mechanism than with it, despite the higher associated expected costs. As notes Robert Stavins (2005) about the price cap, *"this mechanism is only triggered if costs are unexpectedly high, whereby the safety-valve offers important economic protection, while still providing powerful incentives for emissions reductions. If environmental advocates are right, and compliance costs are low, the safety-valve will not be activated."*

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 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.

Another way to consider the appropriate level of price is to consider the development of climate-friendly technology and their estimated costs. For example, there is a wide-spread opinion that carbon dioxide capture and storage will become an indispensable element of any comprehensive climate strategy, for it will allow using abundant fossil fuel resources, especially coal, to fuel the world economy while preserving climate stability. Coal-rich countries, and coal-rich regional entities, are especially keen to see such technologies developed and disseminated. However, except in some cases of enhanced fossil fuel exploitation, capturing and storing the CO_2 will always add a positive cost to using fossil fuels. This cost could be in the range of USD 25 to 50 by 2030 (IEA, 2004). A credible policy to mitigate climate change, at the local level in coal-rich countries or regions, as well as at the international level, will need to drive abatement at such costs at some point in its development.

One may also wonder which country or stakeholder would mostly benefit from the choice of flexible options with price-capping mechanism. This may depend on the revision of a target once a price cap or an indexation rule has been set. If the target is left the same, expected costs are greatly reduced but expected benefits, though in a much lesser proportion, are reduced too. Therefore, the more flexible target should be set more tightly to entail at least equal expected benefits, for the important reduction in expected abatement costs (by comparison to fixed targets) would not be gained at the expense of those who receive most of the environmental benefits. Still, those countries bearing the bulk of the abatement costs would in such case perceive all the benefits associated with the choice of more flexible options.

Further tightening the target would simultaneously entail, by comparison with fixed targets, lower expected costs and higher expected benefits – a "win win" situation likely to facilitate negotiation – up to the point where a still more ambitious flexible target would entail the same original expected costs than the fixed target. In such case, all the benefits of the added flexibility would go to the environmentally beneficiaries of the climate policy.

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 flexible instruments offer them increased flexibility to accommodate different views about the likeliness of various possible environmental consequences as well as various beliefs about mitigation costs.

If there is deep uncertainty about climate change damage, fixed targets as well as more flexible options will be selected mainly on the basis of a perceived environmental risk and the best guessed abatement costs. The willingness-to-pay for mitigation will thus be the main factor. Selection of parameters associated with more flexible options – fixed targets and price caps, indexed targets or others – will similarly depend on willingness to pay. In any case, the economic implications of the mitigation decision will be part of the decision. There is no significant difference between options in this respect; preferring fixed targets over more flexible options does not demonstrate that a greater weight has been given to the "environmental" side of the issue versus its "economic" side. Quite to the contrary, using a more flexible option would simply allow selecting a more ambitious target with the same expected costs but higher expected benefits. In other words, a lower certainty to reach the emission and concentration levels associated with (a succession of) short term fixed targets would offer a greater probability of achieving lower emission and concentration levels.

5. The four dimensions of flexibility

Price caps and indexed targets are not the only 'new' options to consider. Beyond these and non-binding targets for developing countries, which can be analysed as target with a (zero) price cap, many other proposals have been made (Philibert 2005a). In this section we will consider how these various options fare in respect with various dimensions of flexibility. These dimensions need to be explicated first.

The quest for flexibility has been quintessential to the building of international architecture of commitments against climate change thus far. It might be useful to distinguish four distinct dimensions of flexibility, and consider synergies and trade-offs between them. These are the 'where', 'who', 'when' and 'where to" flexibilities. This fourth dimension – the "where to" flexibility – is less recognised but no less important.

The 'where flexibility' reduces the costs of achieving a given short term target, in allowing the emission abatements to take place wherever they cost the less. The 'where flexibility' can be provided by carbon taxes (provided they are uniform over the world), and tradable permit schemes. It rests on the fact that long-living greenhouse gases fully mix in the atmosphere in a few days, therefore the geographic origin of emissions is irrelevant for the main greenhouse gases, though not for the precursors of tropospheric ozone.

For the where flexibility to deliver its potential, it is important to be global. Some argue that developing countries should not be burdened with carbon mitigation until significant steps have been taken in industrialised countries. This formulation is seriously misguided, argues Socolow (2006), for *"much of the world's construction of long-lived capital stock is in developing countries. Unless energy efficiency and carbon efficiency are incorporated into new buildings and power plants now, wherever they are built, these facilities will become a liability when a price is later put on CO_2 emissions"*. Advanced technology should be introduced in developing countries no later than in industrialised countries. However, the introduction in a single action framework of countries with *"common but differentiated responsibilities"*, as the UN Convention on Climate Change acknowledges, introduces the need for a second dimension of flexibility, the "Who flexibility".

The 'who flexibility' is the ability to allocate efforts in a manner felt acceptable by all parties while maintaining cost-effectiveness. This is an inherent feature of tradable permit schemes, but not taxes. The use of taxes would require side-payments. Arguably, these first two dimensions of flexibility may be a fundamental reason why the international community in 1997 selected tradable permit scheme as the backbone of the Kyoto Protocol. However, uncertainties on business as usual emission levels may still prevent developing countries to adopt firm and fixed emission targets – unless they were given sufficient amount of allowances to cover the highest emission growth scenarios. This would not lead to a very effective global framework, as industrialised countries would likely need to buy large amounts of surplus allowances before triggering any real emission reductions in developing countries. Moreover, even in this case the fear of future tightening these targets is likely to dissuade developing countries to sign up such deal. Some more flexibility may be required.

The 'When flexibility' increase the cost-effectiveness in achieving a given long term target. It could be provided by taxes or, in the context of emissions trading schemes, by banking and borrowing, or (very) long commitment periods, or price floors and caps. Banking is fine but would only be effective after initial periods where market players can accumulate allowances to face price spikes. Creating the conditions for this would delay action. Borrowing has proven effective in domestic policies but seems problematic in international setting, as it requires a strong compliance regime that could extend over decades. If "when flexibility" rests on long commitment periods, it may necessitate decisions on long term goals, which may be premature as uncertainties loom large about future costs and benefits of climate policies. Allocating allowances long time in advance of commitment periods would create some kind of liability, even if allowances are denied the nature of "property rights", which may end up difficult to modify at a later stage. This brings us to the fourth dimension of flexibility – the "where to" flexibility.

The 'Where to' flexibility is a way to achieve economic efficiency by making the final result partially dependant on actual costs. The degree of desirable "where to" flexibility depends on the specifics of the problem at stake; in case of climate change, an important degree seems warranted. This arises from the many uncertainties that fraught the problem, on both climate damage and abatement costs. They have prevented any agreement thus far on the precise level and agenda for achieving the ultimate objective of the convention – stabilisation of greenhouse gas atmospheric concentrations.

The 'where to flexibility' might result primarily from periodic reassessments of relatively short term objectives in light of past abatement costs, technology prospects and new insights from the climate sciences and assessment of impacts and adaptation possibilities. This necessity may rule out very long commitment periods. Price caps or other flexible instruments are not only compatible with "where to" flexibility, in fact they would expand it inside the commitment periods. With taxes, the exact amount of abatement in any period will depend on actual costs. With price caps, likely to facilitate relatively more ambitious targets, if abatement costs turn out as expected or lower, the target will be reached. If abatement costs turn out higher than expected, some emissions beyond the target will take place, though limited by the price to pay. Adjustments to actual price would thus be continuous, while adjustments to new scientific assessments would remain periodical.

This is all the more welcome given the cumulative nature of the climate change problem. In any relatively short period of time, marginal abatement costs will depend on the amount of abatement undertaken, while marginal benefits will remain mostly constant, for the global CO_2 emissions of, say, a year, only represent about 1% of the atmospheric CO_2 content. Unless it is toothless, a fixed target always risks entailing marginal costs higher than marginal benefits. And many governments, facing uncertain abatement costs, will tailor their targets on the most pessimistic cost assessment. It may be needed to bring them on the safe side from an economic perspective first before they could bring us all on the safe side from an environmental perspective.

So let us summarise. 'Where flexibility' can be provided by taxes or permit schemes. 'Who flexibility' is only given by permit schemes, unless side-payments are conceivable along with taxes. 'When flexibilities' can result from taxes or permit schemes with long commitment periods, price caps or borrowing – if the latter could be trusted. 'Where to flexibility' seems hardly compatible with long commitment periods. So taxes provide 'where, when and where to flexibilities', but not so easily 'who flexibility', while permit schemes provide 'where and who' flexibilities. Finally only permit schemes with price caps seems able to provide for the four dimensions of flexibility – where, who, when and where to.

All these dimensions of flexibility are equally important. 'Where and when flexibilities' are essential for cost-effectiveness. In a long term issue cost-effectiveness not so much 'getting a given environmental result for the cheapest possible cost' than 'getting the best environmental results for a given expense'. In a world of uneven levels of development, the 'who flexibility' is an essential political ingredient. With respect to continuously adjusting the level of action to concrete affordable possibilities the fourth dimension – the 'where to' flexibility – is no less important and the key to full efficiency, or capacity to match costs and benefits, when uncertainties are only very progressively resolved as time passes.

6. 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-capping mechanism into an emissions trading system or indexing assigned amounts on actual economic growth would reduce expected costs more than expected benefits. It could facilitate the adoption of mandatory action by a broader set of countries, as explains the US Senator Bingaman (2005), elaborating on the uncertainties about abatement technologies and costs, which led the US' bipartisan National Commission on Energy Policy to insert a price cap into its proposed country-wide CO_2 emissions trading system: *"Rather than spending several more years paralyzed by differing climate change modeling assumptions, the safety-valve allows us to begin, albeit cautiously, to reduce U.S. greenhouse gas emissions while protecting our economy. This has been a very useful tool in persuading Members of the Senate that we can begin to take mandatory steps that they won't regret."* Cost uncertainty, however, may not be the only issue that stops governments from adopting mandatory targets.

Price-capping mechanisms would also make possible to define emission quotas relatively more ambitious than without such mechanism, entailing lower expected costs while bringing higher expected environmental benefits. The certainty on near term emission levels offered by fixed targets thus appears of little economic value, compared to the possible 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 actual 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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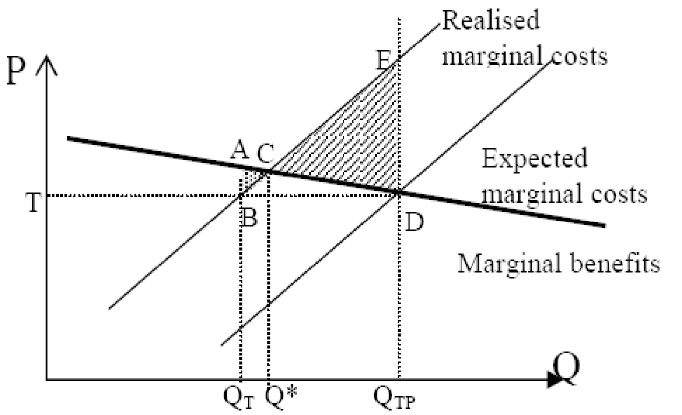
Appendix : Prices versus Quantities – a graphic representation

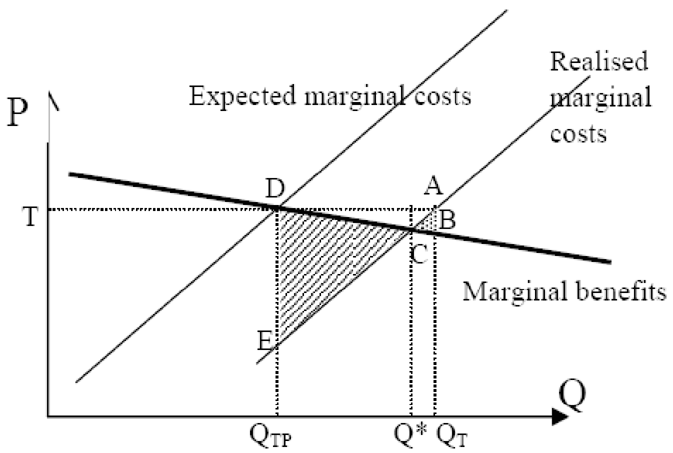
These figures illustrate the relative losses of welfare (by comparison to the optimum) that may arise from different policy choices in the context of cost uncertainty. The first two figures show that when the marginal cost curve is steeper than the marginal benefit curve, the choice of a price instrument 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 5: Flat benefits, higher-than-expected costs



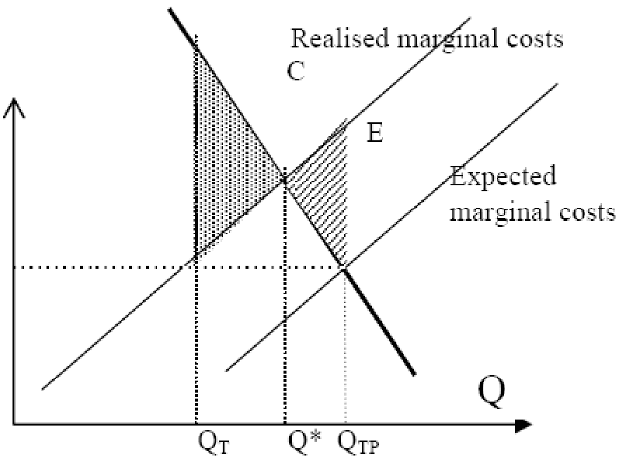
T is the level of a tax that would equalise expected marginal costs and benefits. Q_{TP} is the equivalent quantity of tradable permits. Ex post efficient amount of emission reduction is Q. In this case, costs have turned out higher than anticipated. Q_T is the quantity delivered by a tax after cost 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 6: Flat benefits, lower-than-expected costs



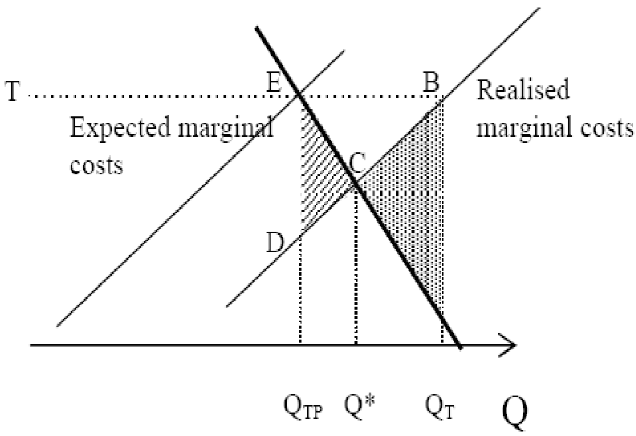
Now the abatement costs turn out to be lower than expected. However, the welfare loss associated with the tax, ABC, is still lower than that of the permit programme, CDE. The quantity delivered by the tax is again closer to the optimum than that delivered by the equivalent (under best guess) quantitative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

Figure 7: 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 8: 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.

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-six of the OECD's thirty member countries. The basic aims of the IEA are:

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- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on the international oil market.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
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