Consilience

SCHOLARLY ARTICLE

Uncertainty and Climate Change Intervention: An Introduction to the Economics of Climate Change

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Abstract:

The pressing reality of global climate change has resulted in a great deal of focus on proposals for market-based government intervention. Currently proposed intervention can take one of two forms: either it can achieve reductions in carbon emissions by controlling the quantity of allowable carbon emissions or it can do the same by setting the price of carbon emissions. If we approach the issue of climate change as a classic externality problem and assume perfect information, economic theory suggests that an optimal level of carbon abatement can be achieved by either method. But, with the issue of climate change we are dealing with a host of unknown costs and benefits of abatement, and we cannot be sure that either method will be efficient. Thus, the role of uncertainty must factor into any policy decision. In this paper, we apply theoretical concepts of informational uncertainty to the issue of climate change. We find that depending on the curvatures of the costs and benefit functions, one type of government intervention may be preferable to the other, with arguments made for each case. Our analysis will highlight the need for further research into the anthropogenic causes and effects of climate change, as well as the need for policymakers to consider the role uncertainty and the precautionary principle play when deciding what sort of government intervention policy to pursue.

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An Introduction to the Economics of Climate Change:

The pressing reality of global climate change has resulted in a great deal of public attention and, increasingly, proposals for some form of market-based government intervention[2]. Policy proposals like a carbon tax or a tradable permit system are becoming common parlance in the political dialogue with some of these policies even being implemented at various regional levels in Europe and the U.S. And although the urgency of the situation (and the long history of inaction with reference to it) may be such that some policy is better than no policy, from an economic standpoint, one is obligated to take a hard look at the factors that may make one sort of policy superior to another in terms of achieving the desired amount of carbon emissions abatement efficiently. Although in a theoretical world of complete information any incentives-based intervention mechanism would be able to achieve the same socially optimal outcome, the reality is that, especially as pertains to the issue of climate change, uncertainty plays an important role. Thus, there is a need to look at the way uncertainty about the causes and effects of climate change affects the level and type of intervention that should be implemented. In this paper we look to apply economic models of externality control to the issue of choosing an efficient form of government intervention, focusing explicitly on the role that uncertainty plays. We will also look at some recent examples of climate change intervention, such as the ETS or RGGI, in light of this conceptual analysis.

Taking a step back, one can think of climate change as being a classic externality problem brought about by market failure. Man's profligate use of fossil fuels from the late 19th century to the current day can be seen as having an associated negative externality, carbon dioxide emissions[3], which bring about adverse social consequences in the form of global climate change. We can think of such social consequences as the costs borne by society as a result of global warming: decreased crop yields, increased flooding, and rising sea levels. Up to now, producers have been able to emit carbon into the atmosphere at no cost, resulting in a 'socially inefficient' level of carbon emissions, currently measuring around 7 billion tons annually. This situation arises because the "true" social cost of burning fossil fuels has not been sufficiently internalized in the price of petroleum-based products.[4]

The subsequent social bads[5] that occur from climate change can be thought of as the negative externalities of anthropogenic carbon emissions, insofar as human-induced emissions affect the climate. Any intervention would thus need to be aimed at correcting this market failure to arrive at a socially efficient level of carbon emissions. In this case, this would involve a level of carbon emissions which ensures that the negative effects of climate change brought about by the increased carbon emissions is in line with the benefits resulting from the use of fossil fuels[6]. Figuring out where this social optimum is and what type of policy to use is a difficult matter. As mentioned earlier,

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[2] Although traditional 'command-and-control' policies of intervention are also possible, it seems that given the significant economic dimensions of the problem of climate change, most economists would agree that market-based mechanisms would be desirable from an efficiency standpoint. But that is another argument for another paper. Here, we focus solely on market-based policy measures.

[3] Of course, it isn't *just* carbon dioxide, but I use the term to refer to all manner of anthropogenic greenhouse gases.

[4] In an idealized economic setting, when companies make production decisions, they look at their own costs of production versus the benefit of selling the result. A more broad view of costs takes into account the damages that accrue to society at large as well.

[5] A "bad" is simply economics jargon for the opposite of a "good." A good is anything that people gain utility or happiness from consuming while a bad is something that causes disutility like garbage or pollution.

[6] This level of emissions is unknown. Indeed, this uncertainty is a big part of the key problem discussed in this essay. The general consensus seems to be a level of emissions that can hold global atmospheric GHG concentrations to below 500ppm (currently 380ppm). But once again, there is a great deal of uncertainty here.

uncertainty over the causes and effects of climate change--for example, the extent to which carbon emissions are to blame--can complicate the picture. In this paper, we will apply a theoretical model to the issue of climate change to see how uncertainty should influence our decision as policymakers in deciding what sort of intervention to use and at what level.

Leaving aside direct mandatory regulation by government agencies, there are two broad approaches to such intervention. A central planning body can either set an explicit cap of the amount of emissions permissible by issuing permits to polluters[7] (and allow some form of trading of permits to operate from there), or it can fix the effective price of the pollutant by levying a tax on its emission (or by subsidizing its reduction). Both options, in a sense, rely on self-interested profit or utility maximization to achieve the policy goals in a decentralized fashion. In the context of climate change, we can think of the former approach as being the "quantity mode," applying to policies such as cap-and-trade or tradable permits schemes. The latter approach constitutes the "price mode," which involves establishing some sort of price associated with emissions in the form of a Pigouvian tax[8]. In both modes, the proper level of intervention depends on where the social optimum is reached.

Theoretically, both types of policies aim to do the same thing: to reach equilibrium where the difference between the social benefits of reducing emissions and the costs of doing so is maximized. In principle exactly the same information is needed to correctly specify the right price or quantity of carbon abatement.[9] However, there may be particular settings and practical reasons for choosing one over the other. To see how this results, we need to first build a model using a bit of basic microeconomic theory.

Let us take carbon emissions reductions as the commodity of interest[10]. Also, let us denote the quantity of carbon emissions reduced as "q." Finally, the costs associated with reducing carbon emissions by amount q and the benefits associated with reducing carbon emissions by amount q can be denoted according to the following notation:

i. q = Quantity of carbon emissions reduced
ii. C(q) = The cost function of reducing emissions by q
iii. B(q) = The benefit function of reducing emissions by q

We will also make a few simplifying assumptions, namely, that $B''(q) < 0$, $C''(q) > 0$, $B'(0) > C'(0)$, and $B'(q) < C'(q)$ for sufficiently large values of q.[11] For the most part, we can assume that these assumptions hold for an externality case such as this, but for the sake of completeness, let us check each assumption one by one. First, $B''(q) < 0$ implies that there are decreasing marginal benefits to reducing emissions. This seems to make sense because the marginal benefits of reducing emissions will probably decrease as the overall reduction becomes larger. To illustrate, say we were to push global CO_2 emissions down to the point where net annual anthropogenic emissions would be zero. In such a case, there would arguably be very little marginal benefit to further reductions, since anthropogenic

[7] The largest polluters in this context, that is, the largest emitters of carbon dioxide, would be energy, heavy industry (such as concrete or steel production), transportation, and agents of deforestation.
[8] A Pigouvian tax is a per unit tax on emissions of a given pollutant, paid by the polluting agent.
[9] Weitzman, M (1974) "Prices vs Quantities," *The Review of Economic Studies*, Vol 41, No. 4, pp477-491
[10] We take reductions instead of emissions themselves simply as a matter of convenience. It is a bit more expedient to model the commodity as a "good" because this allows us to refer to "costs" and "benefits" as the costs and benefits of producing more of something (which is more intuitive than taking about the costs of producing less pollution, although there is no technical reason why we could do the same analysis with the commodity being a "bad").
[11] Where Z' and Z" indicate the first and second derivative of the function, respectively.

sources would no longer be adding to global warming. Second, $C''(q) > 0$ means we have increasing marginal costs of abatement which will undoubtedly increase as the extent of reduction increases, presuming that firms will choose the cheapest way to reduce emissions first, and expend more resources to squeeze out extra reductions. Third, $B'(0) > C'(0)$ simply means that, initially (that is, in a "business-as-usual" scenario), the marginal benefit of reducing a unit of carbon emissions exceeds marginal cost. This is somewhat obvious; otherwise, there would be no gains to be made in overall social utility from reducing emissions, and we would not be having this discussion to begin with. Finally, $B'(q) < C'(q)$ for sufficiently large q just means that, at some point, the benefits of reducing emissions are overtaken by the costs. In other words, the optimum level of reductions will not be infinite--or, to flip that statement around, the optimum level of emission will probably not be zero (as it rarely ever is)--given that we definitely derive a great deal of efficiency from being able to burn fossil fuels cheaply[12].

Given these assumptions, we can now set up the basic planning problem for a governing body. Note that, because climate change is by nature a *global* problem, ideally we would want to think at a global scale. But because there are numerous problems with doing this[13], we generalize to the level of some unspecified large economic organization, and take the central planning agent as some government body (be it sub- or supra- national). Essentially, the problem comes down to finding an optimal quantity of emissions reductions, q*, that maximizes B(q) – C(q). This solution is found where B'(q*) = C'(q*), i.e. where marginal benefits equal marginal costs, and where p* = B'(q*) = C'(q*), or the resultant price of carbon is equal to the aforementioned marginal costs and benefits as well. In other words, our optimal level of emissions reductions will be where the incremental benefit (in terms of damages prevented) of reducing carbon emissions by one extra ton is equal to the costs (in terms of utilizing more efficient technologies, for example) of reducing emissions by that extra amount.

This is an important result. The "socially optimal" level of emissions reductions is where the marginal benefit of achieving more emissions reductions is equal to the marginal cost of reduction. (Perhaps we can think of the benefit of more emissions reduction as the marginal benefit of holding off global warming by x-degrees and reducing damages caused by increased climatic volatility by a certain percentage.) Let us denote the marginal costs incurred by industry in reducing carbon emissions as MC (marginal abatement costs), and the marginal benefit derived by society from such reductions as MB (marginal social benefit). Once again taking Q as the quantity of emissions reductions (so that industry now incurs the costs of "producing" a higher Q and society reaps the benefits of doing so), we can depict this result as follows:

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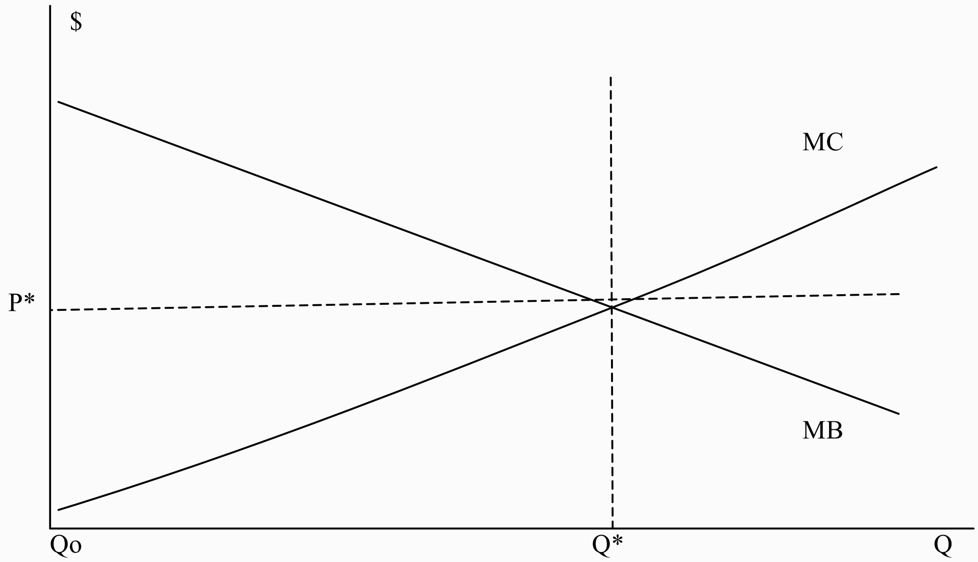
[12] Of course, this condition gets complicated when we introduce a temporal element into the model. It may actually be optimal to produce *negative* CO_2 emissions for any given period of time (minimizing the flows) if we were to try to achieve a lower overall CO_2 concentration (to decrease the stock) in the atmosphere to minimize global warming. But, leaving this element aside, and taking the issue of emissions reductions as a single-period event, we can expect the above condition to be appropriate.

[13] To do so, we would need to gloss over some distinctions found in a more conventional emissions-related externality problem, since there would be no separate 'winners' or 'losers.' We would need to generalize to assume that society as a whole benefits from the cheap energy provided by generating large amounts of carbon emissions through use of fossil-fuels, and likewise society as a whole incurs costs. Instead, we take two separate players, one as "industry" which incurs the cost of emissions reductions, and the other as "society" which derives benefits from it. The role of the government, then, is to intervene in a way that allows these two entities to come to a socially optimal equilibrium.



As we can see here, in the absence of any government intervention internalizing the benefits of reducing carbon emissions, the optimal level of reductions will be Qo or zero, since this will allow industry to minimize costs. With government intervention, however, the societal benefits of reducing emissions becomes internalized, and the socially optimal quantity of reductions Q* is reached. We can think of this dynamic as either society "paying" industry to reduce its emissions insofar as the marginal benefits of doing so are greater than the costs, or as government granting industry the right to emit a certain amount. This initial allocation will depend on the way permits are allocated (whether they are granted freely or auctioned off to firms) or the way the price is structured (whether it is administered as a tax or a subsidy). Whichever way, the end equilibrium q* and p* are theoretically the same.

Were we to assume complete information, it would make no difference whether the government announces q* or p* since, hypothetically, it should be able to figure out both. But obviously the world is much too complex a place for such an assumption to be even remotely true. Thus we need to introduce an element of uncertainty into the model. Inadequate information or uncertainty about the cost- and/or benefit- functions can influence the government's decision in choosing which mode of intervention to implement. In the context of climate change, the sources of such uncertainty arise primarily from technological factors on the costs side, and uncertainty about the causes and effects of climate change on the benefits side.

On the cost side, we must first note that the government, in order to develop an aggregate cost function, must know what the cheapest way is for each firm in the economy to achieve various levels of emissions reductions. This is very hard for any government to do even with cooperation from firms. Furthermore, the technologies involved are changing constantly, and thus the costs of reducing emissions are also changing. To take one example, the relative prices of power generation change with the development of different alternative energy sources. If we assume that burning coal has a much higher carbon emissions per megawatt-hour generated than, say, wind, we can see that the price of reducing any amount of carbon emissions by switching over from coal to wind will depend on a multitude of technological factors including the dollar-cost/megawatt-hour of wind energy[14], the market price of

[14] This price, incidentally, has dropped in fits and starts over the past few decades as larger, more efficient turbines and wind blades have been developed.

coal, the energy-efficiency of the coal plant with which we started, the cost and effectiveness of coal liquefaction technologies at the time, and so on.

On the benefits side, the function is even more complicated, as it is affected by the complexity of the climate system and the relationship between climate, ecosystems, and economies. Uncertainty over the causes of climate change translates directly into uncertainty over the benefits of reducing carbon emissions by any given amount. If we are in any way unsure to what extent anthropogenic emissions are responsible for global warming, we cannot be certain about the exact marginal benefits of reducing them. To choose an extreme example, if it turns out that global warming has less to do with carbon dioxide emissions and more to do with some other variable (say orbital patterns that create long-term fluctuations in Earth's climate over tens of thousands of years) then reducing emissions will do little to curb global warming[15]. To put it in terms of our model, how directly relevant carbon emissions are to the causes of climate change will determine the shape of the benefit function (making it more or less curved, kinked, etc.).

Finally, there is additional uncertainty over the way effects of climate change will influence the benefit function in terms of the varying sensitivity of our economies to climate change. For example, if there is a possibility that global warming causes "bad" effects such as droughts in inland climes, but also leads to "good" effects such as lengthening of growing seasons in northern latitudes and opening of arctic sea lanes for transport, our benefit function becomes that much more complicated to manipulate and dependant on uncertain variables[16].

Thus, we need to incorporate all of the above elements of uncertainty into our model. We do this by introducing "disturbance terms" or "random variables" into the cost and benefit functions as follows:

iv. $C(Q) \rightarrow C(Q, \theta)$

v. $B(Q) \rightarrow B(Q, \eta)$

$C(Q, \theta)$ and $B(Q, \eta)$ represent the cost and benefit functions of reducing carbon emissions over a range of stochastic random variables. Ideally, we would find a way of breaking down variables θ and η into a schedule of probabilities, in which case we would be able to create a plan where the ex ante ideal of $B(Q^*(\theta, \eta), \eta) = C(Q^*(\theta, \eta), \theta) = p^*(\theta, \eta)$ is satisfied over an entire schedule of contingent levels of intervention. However, these random variables are for obvious reasons quite difficult to quantify[17]. Moreover, it would be very inefficient to administer policies that would either change the specified level of taxation or alter the total quantity incrementally every time new information arose.

So the government needs to choose a mode and level of intervention without knowing with certainty whether it constitutes the optimal solution. In fact, given the uncertainty, we can say that the government will invariably be locking itself into certain less-than-ideal consequences - where $B(q^\wedge, \eta) \neq C(q^\wedge, \theta)$, q^ being the quantity set through a tradable permits system, or where $B(q\sim(\theta), \eta) \neq C(q\sim(\theta), \theta)$, q~ being the quantity arrived at given a

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[15] Of course, the general scientific consensus is that this is highly unlikely, and global warming is, in fact, being caused primarily by human activity, but the point is that we still have only a vague understanding of how *reducing* carbon by any given amount will affect the overall damages brought about by climate change.

[16] It is also worth noting here that the time structure of the problem of climate change--the fact that whatever policy we choose, the "costs" of taking action will be incurred in the present while the "benefits" will only materialize far into the future--affects the way we measure the benefits and costs. Insofar as uncertainty over the effects of climate change affects our discount rate (social rate of time preference) it will have an effect on how the future benefits are valued today.

[17] Although the recent Stern Review on Climate Change recently takes a stab at doing just that.

price p set by a tax on carbon. A good example of having to live with less than optimal consequences of an intervention for a certain period of time was phase one of the current European Emissions Trading System (ETS). The general consensus is that European governments handed out too many emissions permits to existing power plants and factories free of charge. This caused the price of emissions permits to fall to well below 1 € per ton in the first phase of the scheme, which ends this year, and a clear under-reduction of emissions (i.e. a less than optimal level of q*) during this first period[18].

As a result, it is clear that neither instrument yields an optimum ex poste, so the relevant question is which comes closer under what circumstances. If we define Δ as the comparative advantage of prices over quantities (as Weitzman does), we find that $\Delta = E[\{B(q\sim(\theta),\eta) - C(q\sim(\theta),\theta)\} - \{B(q\hat{}, \eta) - C(q\hat{}, \theta)\}]$[19]. In other words, the comparative advantage of prices over quantities as a policy setting choice is equal to the expected value of the difference between the overall benefit of setting a quantity q^ of optimal emissions reductions (given random variables θ and η) and that of setting a price of emissions reduction that clears at q~. With a bit of algebra, we arrive at the following result: $\Delta=\sigma^2 B''/2C''^2 + \sigma^2/2C''$. Effectually, this implies that, all other factors netting to zero, the sign of Δ is determined by the sign of C" + B". In other words, the advantage of setting prices is negative if B has more curvature than C, and vice versa, holding the other terms constant.

To illustrate, let us assume that there is always a discrepancy between what the government anticipates will be the marginal cost of emissions reductions, and what actually occurs. We can depict this as the two different MC curves, "MC anticipated" and "MC actual," in the graph below.

From the graph we can see that, if the government sets its level of intervention according to "MC anticipated," both the q-setting and p-setting policies will result in a total amount of reduction that is inefficient. "QC," the resulting quantity of reductions when a cap is imposed, is, in this case, too low and results in an efficiency loss of "ELC" (Efficiency-loss from Cap). "QT," the resulting equilibrium quantity of reductions when a tax of t is imposed, is, in this case, too high and results in an efficiency loss this time of "ELT" (Efficiency-loss from Tax). One can see that changing the slope of the marginal benefit or marginal cost curves will determine which of these two losses are greater. Effectively, ELC will decrease as the MB curve becomes steeper, making a q-setting option more desirable, and likewise, ELT will decrease as MB curve becomes flatter, making a p-setting option more desirable.

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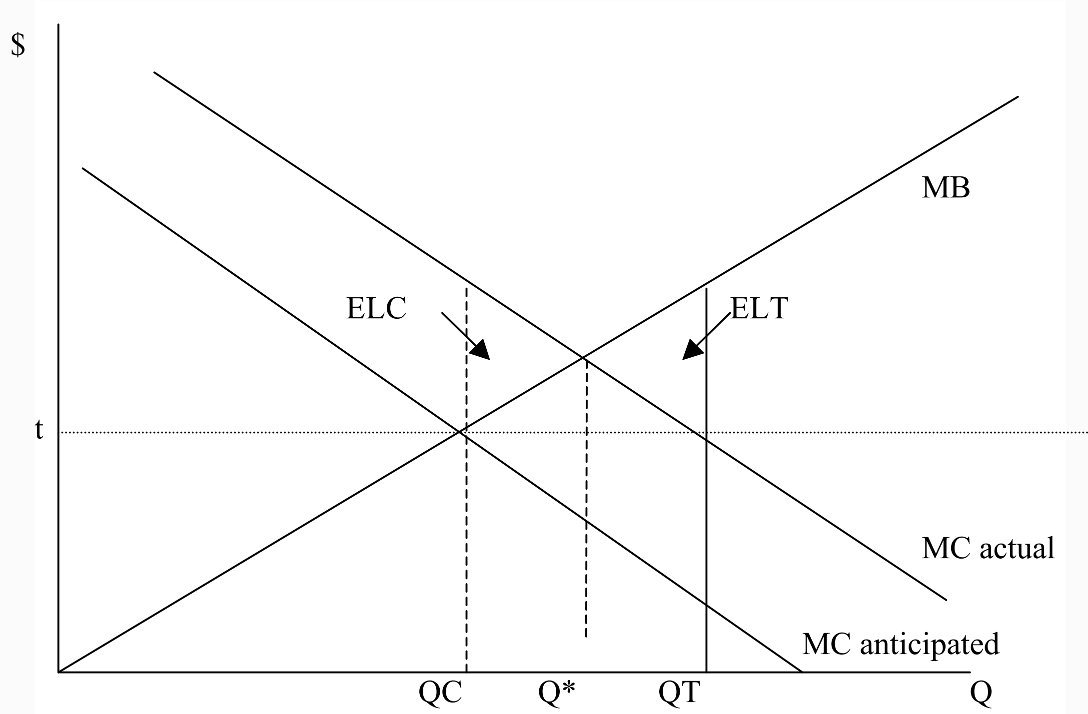
[18] Source: Point Carbon. http://www.pointcarbon.com/Home/Market%20prices/Historic%20prices/article8723-633.html

[19] Weitzman, M (1974) p 483.



In the context of global warming, we can infer the following from the model used above. First, if the benefits of emissions reductions are sharply curved--for example, if the marginal benefits of reducing emissions in terms of damages averted are great--it would be preferable to implement a quantity-setting policy such as a cap-and-trade scheme. This would also be true if reducing emissions by less than a certain threshold amount would lead to disastrous consequences. Likewise, if the cost function is linear such that the marginal costs of reducing emissions are flat, we can expect the smallest miscalculation of a set carbon credit price (i.e. the price of reduced emissions) to lead to huge changes in the resulting overall *quantity* reduced. This makes the price-setting strategy that much riskier and thus, less desirable.

We can draw two more inferences from the above result. The first is that the final or intermediate nature of our commodity (here, greenhouse gas emissions) can tell us something about which policy tool might be the better choice. Specifically, the more final the commodity, the more curved the benefit function, in which case quantity-setting would be a better option. The second result is that the number of units engaging in emissions reductions can also affect the advantages of using one mode over the other. Weitzman's results[20] tell us that, all other things being equal, in situations with more rather than fewer independent units utilizing different technologies and producing outputs which substitute for each other in yielding benefits, there are correspondingly greater relative advantages to the *price* mode of control. Using prices will allow the government to automatically screen out high cost producers and encourage more efficient ones to reduce to a greater extent.

So where does all of this leave us? For one thing, it is very clear that uncertainty plays a crucial role in how we approach policy interventions concerning climate change. If anything, our analysis should highlight the sensitivity

[20] We need some more algebra to show this mathematically, but I have left it out in the interest of time. They can be found on page 488 of Weitzman, "Prices vs Quantities."

of government policy to information available from both the private sector and the scientific community, as well as emphasize the importance of further research on both sides of the equation (technological factors on the cost side, and climate science and state-dependant economic modelling on the benefits side). As far as there is still a great deal of uncertainty over the extent to which climate change will affect our economies in the future, as well as the extent to which reducing emissions now will actually have a positive effect sometime soon, it is impossible for government to know the exact level of emissions reductions that would constitute the social optimum.

In terms of evaluating different types of intervention however, arguments can be made for and against each mode. Quantity-setting methods such as tradable permits schemes or cap-and-trade system would probably be a safer choice if we consider the longer term. First, it seems more likely than not that the benefit function will be very steeply curved if we consider it across a longer time horizon. This would be so because the benefits, though taking a long time and a large amount of reductions to materialize, would nonetheless be very significant given the potentially disastrous degree of damages forestalled (although, as alluded to before, the issue of temporality and discounting can confound this quite a bit). It also seems that quantity-setting would be more appropriate given that carbon emissions reductions are a final good (in terms of not having very many other *uses*) unless, of course, we find alternative technologies that make carbon emissions reductions more of an intermediate good[21].

The argument for p-setting (i.e. a tax on emissions) in this context may be that, because there are so many different units (tens of thousands of factories, power plants, locomotives, etc.) producing a highly substitutable good (100 tons of carbon reduced by a factory in New York has roughly the same effect on the atmosphere as 100 tons reduced by a factory in New Zealand), setting a price and letting the market work out the level at which all the units have equalized marginal costs (within industry) may be more efficient. One might also argue that, because global climate change is chiefly an issue of the *stock* of greenhouse gases in the atmosphere and not its flows, the marginal benefits of reduction may actually be quite flat. This is true at least in the short term.

Given the potentially disastrous consequences of global warming in the longer term, it seems that specifying a quantity target for emissions reductions in conjunction with a certain price ceiling (which would kick in if the resultant price of carbon exceeded a certain predetermined amount) and allowing for units to find the cheapest ways to reduce emissions and to trade credits amongst polluters would be a better, safer bet. As with most environmental issues of this magnitude, as well as the potential for disastrous consequences, adopting the precautionary principle seems to be prudent in choosing the right policy package to deal with global climate change. Of course, we have said nothing about the political complications of either policy choice. For example, a cap can only be instituted by a governing body with jurisdiction over the area involved, hence the difficulties of a global cap-and-trade system. Likewise, imposing a 'carbon tax' may be a rather tough sell politically, given the general aversion toward new taxes. Nor have we made any considerations of equity or distributional fairness, both within countries and across international economies[22]. All of these factors must no doubt be taken into account at some level. The point of using

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21 That is, unless we find an alternative way to reduce the effects of global warming without having to reduce carbon emissions.

22 A critical distributional issue in the context of a cap-and-trade (quantity-setting) mechanism is the method by which emissions permits or credits are distributed at the start of the program. Permits can either be issued freely to polluting agents, or they can be auctioned off at a price. Although, theoretically, society as a whole bears the same total cost either way, where this financial burden falls *within* society (be it to polluting firms or ordinary taxpayers) depends on how the permits are distributed to start with.

an economic model as we have done here is to isolate the economic component of the decision in the particular context of informational uncertainty.

For the time being, it seems that regional initiatives in Europe and the U.S., perhaps for these very political reasons, have gone ahead with putting in place some very limited quantity-setting mechanisms. The major regional initiatives currently underway--RGGI (Regional Greenhouse Gas Initiative) in the North-Eastern United States[23], and the ETS in Europe, as alluded to earlier--follow a cap-and-trade approach aimed at achieving reductions by lowering the total cap gradually. The second phase of the ETS has set out much fewer overall permits, and is scheduled to distribute these permits through auction, which will, many observers hope, result in a more reasonable (i.e. higher) price of carbon. Whether or not these regional schemes prove to be successful in achieving their initial targets, however, it is clear that most of the world economy is still not included in such initiatives and that a fruitful avenue for future research will involve expanding on the results found here.

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[23] It is worth noting that even the RGGI, as it currently stands, includes a "price safety valve" which is currently proposed to expand the compliance period if the resulting price exceeds a certain amount, thus effectually combining elements of both price- and quantity-setting mechanisms.