The Role of Economics in Climate Change Policy

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Climate change presents both a challenge and an opportunity for economists. In broad terms the challenge is familiar to anyone who has spent much time thinking over other social problems: How can we design a policy that addresses the key aspects of the problem as efficiently as possible, but that is also practical enough to be implemented? On top of that, however, climate change poses an additional problem: steering policy makers away from obvious but inappropriate solutions. An easy mistake to make – and one which has been a major obstacle in the policy debate – is to assume that climate change is essentially just another air pollution problem, and that it can therefore be solved by a standard policy. Unlike ozone, particulates, sulfur dioxide and other conventional problems, climate change involves unprecedented time scales, vast uncertainties, and has potentially enormous distributional effects. A realistic policy needs to address these explicitly.

What makes climate change an opportunity is, ironically, that so little real action has been undertaken to date. Most policy issues have long histories of inefficient regulation that can be difficult or impossible to undo. With climate change there is still a chance to get the economics right from the beginning. However, that will not happen automatically. The ongoing negotiations conducted under the auspices of the United Nations Framework Convention on Climate Change have so far produced the Kyoto Protocol, which is deeply flawed (and will be discussed in detail below). The Protocol stands little chance of ratification in the United States but it still may be ratified by Europe. This should serve as a warning that climate change policy could easily take a form that economists and most of the world would ultimately regret.

In the remainder of this article we present the key features of climate change that make it different from other environmental problems and discuss how economic theory can be used to design an appropriate policy. We then review the history of international negotiations and evaluate the Kyoto Protocol. Finally, we conclude with suggestions on how economic theory could be used to move climate change policy in a much more constructive direction.

The Only Certainty is Uncertainty

At the heart of the climate change debate are two undisputed facts. The first is that certain gases in the atmosphere are transparent to ultraviolet light but absorb infrared radiation. The most famous of these gases is carbon dioxide but water vapor, methane, nitrous oxide, chlorofluorocarbons and various other gases have the same property. In 1895, Svante Arrhenius, a Swedish chemist, showed that the presence of carbon dioxide in the atmosphere raises the Earth's surface temperature substantially.[1] Energy from the Sun, in the form of ultraviolet light, passes through the carbon dioxide unimpeded and is absorbed by objects on the ground. As the objects become warm, they release the energy as infrared radiation. If there were no carbon dioxide in the atmosphere, most of the infrared energy would escape back into space. The carbon dioxide, however, absorbs the infrared and reradiates it back toward the surface, thus raising global temperatures. This mechanism is now known as the "greenhouse effect" because it traps energy near the Earth's surface much the way glass keeps a greenhouse warm. Carbon dioxide and other gases contributing to this effect are called "greenhouse gases".

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[1] Arrhenius calculated that removing all carbon dioxide from the atmosphere would lower global temperatures by about 31° C (56° F). The direct effect of removing the carbon dioxide would be to lower temperatures by 21° C (38° F). In addition, the cooler air would hold less water vapor, which would lower temperatures by another 10° C (18° F). For comparison, the actual global average temperature isabout 14° C (57° F), and a change of this magnitude would give Los Angeles a climate roughly like that of Nome, Alaska.

The second undisputed fact is that the concentration of many greenhouse gases has been increasing rapidly because of human activity. Since the Industrial Revolution, deforestation and the use of fossil fuels has raised the level of carbon dioxide in the atmosphere by about 30 percent.[2] Methane is a much smaller fraction of the atmosphere but its concentration has risen even more rapidly: it is now 151 per cent above pre-industrial levels.[3] In addition, the concentration of nitrous oxide has risen by 17 per cent, and all chlorofluorocarbons in the atmosphere are the result of human activity.

Beyond this point, however, controversy begins to arise. Although it is clear that greenhouse gases can trap energy and make the atmosphere warmer, and that the concentration of those gases has been increasing, it is far less clear what those facts mean for global temperatures. A long list of scientific uncertainties makes it difficult to say precisely how much warming will result from a given increase in greenhouse gas concentrations, or when it will occur, or how it will affect different regions and ecosystems.

One challenge for climatologists has been understanding the link between temperature change and atmospheric water vapor. On one hand, higher temperatures increase the rate of evaporation and allow the atmosphere to hold more water vapor. Since water vapor is itself a greenhouse gas, this could lead to positive feedback and exacerbate any temperature increase caused by carbon dioxide. On the other hand, a given increase in capacity does not necessarily imply an equal increase in water vapor since much of the atmosphere is not saturated.

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[2] Ice cores and other evidence shows that the atmospheric concentration of carbon dioxide was about 280 ± 10 parts per million (ppm) for several thousand years before the beginning of the Industrial Revolution. By 1998, the concentration had risen to 365 ppm.

[3] The concentration of methane has risen from about 700 parts per billion (ppb) before 1750 to 1745 ppb in 1998. The sources and sinks of atmospheric methane are less well-understood than carbon dioxide. However, significant anthropogenic sources include agriculture, natural gas production and landfills.

A closely related uncertainty is the role of clouds. Clouds reflect ultraviolet radiation, so an increase in cloud cover could tend to reduce the greenhouse effect. At the same time, they absorb and reradiate infrared, which tends to increase the greenhouse effect. Which effect dominates depends heavily on factors that vary from one location to another: the altitude and thickness of the cloud, the amount of water vapor in the atmosphere, and the presence of ice crystals or aerosols (tiny airborne particles or droplets) in the area. Given current knowledge, it is not possible to say for certain whether cloud formation is likely to amplify or attenuate temperature changes from other sources.

Another problem is determining how quickly ocean temperatures will respond to global warming. Water has a high heat capacity, and the volume of sea water is enormous, so the oceans will tend to slow climate change by absorbing excess heat from the atmosphere. This effect delays warming but does not prevent it: eventually the oceans will warm enough to return to thermal equilibrium with the atmosphere. The time required to reach equilibrium depends on many complicated interactions, such as the mixing of different layers of sea water, that are not completely understood and are difficult to model.

Yet another important uncertainty arises because the role of aerosols in the atmosphere is poorly understood. Aerosols originate from a variety of sources: dust storms, volcanoes, fossil fuel combustion, and the burning of forests or other organic material. They reflect a portion of incoming solar radiation, which tends to reduce climate change, but they also absorb infrared, which tends to increase it. Aerosols are poorly understood in a number of respects but their concentration in the atmosphere seems to be increasing, and their net effect on global temperature seems to be negative.[4] This is particularly true of sulfate aerosols, which arise in part from sulfur dioxide (SO_2) emitted when sulfur-containing fossil fuels are burned. Early generations of the general circulation models (GCMs) used to study climate change did not include aerosols and predicted that past greenhouse gas emissions should have resulted in more warming than has actually been observed. It appears, in other words, that aerosols have partially offset the increase in carbon dioxide during the last century.

Most of these uncertainties are very difficult to resolve. Using a very simple model with limited data, Arrhenius calculated that doubling the concentration of carbon dioxide in the atmosphere from pre-industrial levels would raise global average temperatures by 4-6° C .[5] Today, elaborate climate models based on far more data suggest that doubling carbon dioxide concentrations would raise temperatures by 1.5–4° C.[6] The mean increase is smaller but the range of uncertainty has actually grown, from 2° C to 3° C, as climatologists have become aware of more complicated and subtle mechanisms at work in the atmosphere, such as the role of aerosols.

Partly because it has proved so difficult to predict the future effect of greenhouse gases on global temperatures, many participants in the debate—scientists, government officials, environmentalists and lobby groups—have been interested in finding out whether past emissions have had much effect. Here, too, certainty is elusive. In spite of articles in the popular press that report every hot summer as evidence of global warming and every cold winter as evidence against it, it is actually quite hard to prove that global warming has begun to happen. Normal

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[4] The Third Assessment Report of the Intergovernmental Panel on Climate Change describes the current level of scientific understanding of aerosols as "low" to "very low" (IPCC 2001).

[5] Ice cores and other evidence shows that the atmospheric concentration of carbon dioxide was about 280 ± 10 parts per million (ppm) for several thousand years before the beginning of the Industrial Revolution. Doubling that would

variations in global temperatures are large compared to the change that might have been caused by past emissions of greenhouse gases. It is very difficult to tell whether actual increases in temperature are outside the usual range, and thus hard to tell if greenhouse gases have caused any global warming. What's more, the data do not always agree, in part because over the years, people have measured temperatures with different kinds of instruments, at different locations, and even at different altitudes in the atmosphere. A simple example of this problem is the "urban heat island" effect: over time, temperature measurements have become increasingly concentrated in cities, which tend to be warmer than their surroundings. Without correcting for this effect, average temperatures appear to have increased much more than they actually have.

Current evidence seems to suggest that climate change can be detected in historical data, although climatologists are far from unanimous. In an exhaustive survey of the literature, the Intergovernmental Panel on Climate Change (2001) concluded that during the 20th century, global average surface temperatures increased by 0.6 ± 0.2 °C and that "most of the observed warming over the last 50 years is likely to have been due to the increase in [anthropogenic] greenhouse gas emissions," where "likely" is defined to mean a 66-90 percent probability.[7] This is highly suggestive but it is very important to keep in mind that under the usual statistical standards in economics this result would not be significant: it is *not* possible to reject the hypothesis that the warming is *not* anthropogenic. Put less formally, it is a substantial overstatement of current scientific knowledge to conclude that anthropogenic warming has been detected in historical data. At the same time, however, it is important to remember that all of

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be a concentration of 560 ppm. By 1998, the actual carbon dioxide concentration had risen to 365 ppm and it is likely that the 560 ppm level will be reached some time between 2050 and 2100.

[6] Intergovernmental Panel on Climate Change (2001).

[7] Intergovernmental Panel on Climate Change (2001), *Summary for Policy Makers*, pages 2 and 10.

these measurement problems make it equally difficult to prove that global warming has *not* begun to occur.

In truth, it is impossible to say exactly how much warming has occurred to date, or how much will occur in the next century. Current research summarized in IPCC (2001) finds that the concentration of carbon dioxide in the atmosphere in 2100 is likely to exceed pre-industrial levels by 75 to 350 percent, an enormous range of uncertainty. The source of this uncertainty is essentially economic and very difficult to resolve: predicting the concentration of carbon dioxide in 2100 requires predicting the trajectory of carbon dioxide emissions over the whole century.[8] Other greenhouse gas concentrations are likely to increase as well. Predictions of global average surface temperatures in 2100 show increases of 1.4°C to 5.8°C above 1990, and as large as that range is, it still does not include all known uncertainties. Given the complexity of the processes involved, it is not likely that scientists will be able to reduce this uncertainty for decades.

Moreover, climatology as a whole is only one of several sources of uncertainty that are important for climate change policy. Even if temperature changes could be predicted perfectly, daunting gaps in our knowledge remain. Many of the physical and ecological consequences of temperature change are less well-understood than climatology.

A few of the likely consequences of global warming are clear, although their magnitude is uncertain. Global warming is expected to cause sea levels to rise between 9 and 88 cm (3.5 inches to 2.9 feet) by 2100. Much of this is due to thermal expansion of the upper layers of water in the oceans, with a smaller but significant contribution from melting of glaciers. Contrary to science fiction accounts of global warming, the polar ice caps are unlikely to have a major effect on sea level. Warming is likely to reduce the amount of ice in Greenland but to increase it in the Antarctic, which is thought likely to receive an increase in precipitation. There is likely to be a reduction in sea ice in the northern hemisphere but it will have little effect on the sea level.[9] Two events that would cause a catastrophic rise in sea level – complete melting of the Greenland ice sheet or disintegration of the West Antarctic Ice Sheet, either of which would raise the sea level by 3 m – are now thought to be very unlikely before 2100.

Table 1 gives a brief summary of other possible consequences of global warming, including the relative certainty of each one. Certainty is expressed using the terminology of IPCC (2001): "very likely" means a 90-99% chance, "likely" means a 66-90% chance, "medium" means a 33-66% chance, and "unlikely" means a 10-33% chance. These terms roughly indicate the amount of agreement among climatologists and GCM modelers, and are *not* formal probability estimates. In addition, virtually all evidence suggests that climate change will vary by region: some parts of the Earth will warm substantially more than others, and precipitation will increase in some areas and decrease in others.

Table 1: Possible Consequences of Higher Global Temperatures

Extreme weather events
Increase in frequency of heat waves; higher risk of summer droughts over continental areas at mid-latitudes; more intense precipitation. (Likely to very likely).
Tropical storm intensity
Higher peak wind speeds and more intense precipitation in cyclones, hurricanes and typhoons. (Likely).
Mid-latitude storm intensity
Changes cannot be determined from current climate models.
Atlantic thermohaline circulation

[8] The trajectory of carbon emissions will depend heavily on, among other things, population growth, technical change, income growth, and energy prices, none of which are easy to predict over the next century.
[9] This is true because floating ice displaces approximately the same amount of liquid water.

Differences in water temperature and salinity produce the Gulf Stream and other currents that bring warm surface water to the North Atlantic. Evidence from ice cores indicates that the pattern of circulation can change very rapidly but it is uncertain whether such a change could result from global warming.
Patterns of precipitation
Increase in average global evaporation and precipitation but with substantial regional variability.

These changes in climate are likely to produce a variety of effects on ecosystems and human activities. A short summary is shown in Table 2. All of these effects are less certain than the changes in climate discussed above: they depend on the amount of warming, which is uncertain, but they also involve additional uncertainties.

Table 2: Possible Effects of Climate Change

Energy demand
Increased energy demand for cooling; reduced demand for heating. (Very likely) Net effect varies by region and climate change scenario.
Coastal zone inundation
Low-lying coastal areas in developing countries would be inundated by sea level rise: a 45 cm rise would inundate 11% of Bangladesh and affect 5.5 million people; with a 100 cm rise, inundation increases to 21% and the population affected to 13.5 million. Indonesia and Vietnam would also be severely affected, as well as a number of small island countries. (Likely)
Exposure to storm surge
Global population affected by flooding during by coastal storms will increase by 75 to 200 million.
Human health
Increase heat-related injuries and mortality and decrease cold-related ones. For developed countries in temperate regions, evidence suggests a net improvement. (Medium) Moderate increase in global population exposed to malaria, dengue fever and other insect-borne disease. (Medium to likely) Increase in prevalence of water-borne diseases such as cholera. (Medium) Increase in ground-level ozone. (Medium)
Water supplies
Many arid areas will have a net decrease in available water.
Agriculture

Many crops in temperate regions benefit from higher carbon dioxide concentrations for moderate increases in temperature but would be hurt by larger increases. Effect varies strongly by region and crop. Tropical crops would generally be hurt. Small positive effect in developed countries; small negative effect in developing countries. Low to medium confidence: 5 to 67%.

Extinction of species

Species that are endangered or vulnerable will become rarer or extinct. The number of species affected depends on the amount of warming and regional changes in precipitation. (Likely)

Ecosystem loss

How ecosystems respond to long-term changes is poorly understood. Climate change will affect the mix of plant and animal species in ecosystems. (Likely to occur, but with a substantial lag).

A climate change policy would aim to reduce or eliminate these effects. Its economic benefit, therefore, is the sum of the damages avoided. However, measuring these damages is even more uncertain than calculations of future temperature changes or the resulting environmental effects. Attaching values to some effects is relatively straightforward: for example, calculating the dollar value of a change in net energy demand. Assigning values to others is more difficult. The agricultural damage done by climate change, for example, depends on the costs of adapting crops and farming methods, which vary across regions and are largely unknown. Most difficult of all is assigning a value to changes that are not mediated by markets, such as the extinction of a species or a change in an ecosystem. Economists do not even agree on the methodology to be used in these cases.[10]

Overall, IPCC (2001) concludes that the aggregate market-sector impacts of a small increase in global temperatures could be "plus or minus a few percent of world GDP" (Medium

[10] The main method used to determine what people are willing to pay for environmental goods that they don't use directly is contingent valuation. However, there are serious problems with contingent valuation: see Diamond and Hausman (1994) for a detailed critique.

confidence).[11] Developing countries are more vulnerable to climate change and are likely to suffer more adverse impacts. Larger temperature increases would cause aggregate effects to become increasingly detrimental in all countries.

The cost of reducing greenhouse gas emissions is also uncertain. A variety of studies have been done, most focusing on the near-term costs – through 2010 or 2020 – of one of two policies: reducing emissions to 1990 levels, or implementing the 1997 Kyoto Protocol.[12] Marginal costs are typically measured by calculating the carbon tax (a tax on the carbon content of fossil fuels) needed to achieve a particular emissions target. The results vary substantially across models. For example, the carbon tax needed in the United States to reduce greenhouse gas emissions to 93% of their 1990 levels by 2010 (as would be required by the Kyoto Protocol) ranges from $76 to $322 (1990 US$).[13] The range of estimates for European OECD countries is even larger: $20 to $665.

The wide range of these estimates is due to uncertainties about a variety of key economic parameters and variables. Some of the uncertainties are relatively straightforward econometric issues: for example, the short-term price elasticity of demand for gasoline by households is not known precisely. Other variables, however, are much more difficult to pin down. Population growth and the rates of productivity growth in individual industries are key determinants of the cost of reducing greenhouse gas emissions but neither can be projected with much confidence beyond a few years into the future.

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[11] IPCC (2001), *Technical Summary of the Working Group II Report*, page 70.

[12] The Kyoto Protocol will be discussed in detail below.

[13] The figures in this paragraph are drawn from Energy Modeling Forum 16, a multi-model evaluation of the Kyoto Protocol. The results of the study appear in a 1999 special issue of the *Energy Journal* and were heavily used in IPCC (2001), particularly the Working Group III Report on mitigation.

In summary, uncertainty is the single most important attribute of climate change as a policy problem. From climatology to economics, the uncertainties in climate change are pervasive, large in magnitude, and very difficult to resolve. However, this does not mean that the appropriate policy is to do nothing. Instead, what is required is a coordinated international approach that reduces emissions of greenhouse gases where it is cost effective to do so. We will present one such policy shortly. Before doing so, however, it is important to discuss the second most important attribute of climate change policy: distribution effects. Any serious climate change policy will need to have wide-spread participation over a long period of time and the key to assuring this is to be realistic about distributional issues in the design of the policy.

A Hardheaded Look at Distributional Issues

Economists are trained to worry about efficiency and to leave equity and distributional matters to policy makers. With climate change, however, this dichotomy is untenable. There is no international agency to coerce countries to comply with an agreement they find significantly inconsistent with their national interest, nor is there likely to be in the foreseeable future. Greenhouse gas emissions originate throughout the world and most of countries will eventually need to participate in any solution. However, a treaty that makes heavy demands on national sovereignty, or that has significantly adverse distributional effects, is unlikely to be ratified. In addition, countries that do ratify the agreement would be likely to cease complying as soon as costs became substantial. The Bush administration's decision to abandon the 1972 antiballistic missile treaty is a clear reminder that governments can easily renege on commitments made by their predecessors. A realistic climate policy, therefore, cannot rely on large international transfers to prevent individual countries from being made worse off. In the language of game theory, participation in a climate change agreement must be incentive-compatible for each country.

Unfortunately, much of the debate over the distributional aspects of climate change policy has been focused on a different and far less practical question: Which countries are ethically responsible for reducing climate change? Some observers argue that industrialized countries are obligated to do the most to avoid climate change because they have generated most of the greenhouse gases now in the atmosphere. Others argue that developing countries account for a large and growing share of emissions, and that no climate policy will succeed without significant participation by the developing world. There is some truth in both of these positions but neither is a realistic way to approach designing a policy that will have to be ratified by sovereign nations. Instead, the focus must be on developing a pragmatic policy that will allow all countries to make a firm commitment to cut emissions over time.

In addition, an international climate change agreement needs to allow each participating country to address distributional issues within its borders in a flexible and transparent manner. For example, domestic political considerations might make it essential for a government to compensate people hurt by the policy, or at least to provide some sort of transition relief, such as grandfathering a portion of each existing firm's emissions. An ideal agreement would be designed to allow countries this kind of distributional flexibility without undermining the international transparency of the policy.

Designing a Practical Climate Policy

The uncertainties associated with climate change have polarized public debate. Some observers argue that the uncertainties are too large to justify immediate action – that global warming is a theoretical problem which is not supported by unambiguous empirical evidence. In their view, the best response is to do more climate research and wait for the uncertainties to be resolved. Other observers take the opposite position: that the potential dangers from global warming are so severe that substantial cuts should be made in greenhouse gas emissions immediately, regardless of the cost.

From an economic standpoint, neither position is appropriate. At its core, climate policy is an exercise in decision-making under uncertainty. Increasing the concentration of greenhouse gases in the atmosphere exposes the world to some risk of an adverse change in the climate, even though the distribution of that risk is poorly understood. To put this more formally, each ton of greenhouse gas emissions carries with it an externality: an uncertain amount of damages that might occur in the future as a result of climate change. If the world were risk neutral, the efficient policy would be to abate emissions until the marginal costs of abatement were equal to the expected marginal damages avoided. In practical terms, this would mean abating emissions where possible at low cost. It lies between the two positions that have dominated public debate: even though there are substantial uncertainties, some action should be taken to reduce emissions; because of the uncertainties, however, draconian actions are not justified. In essence, economic theory suggests a policy of prudence: taking reasonable measures to reduce the risk of climate change.

Economic theory also provides guidance about the structure of a climate change policy. Since greenhouse gases are emitted by a vast number of highly heterogeneous sources, minimizing the cost of abating a given amount of emissions requires that all sources clean up amounts that cause their marginal cost of abatement to be equated. To achieve this, the standard economic policy prescription would be to use a market-based instrument, such as a tax on emissions or a tradable permit system for emission rights.

In the absence of uncertainty, the efficient level of abatement could be achieved under either policy. Figure 1 illustrates this point. The horizontal axis shows the amount of abatement as a percent of uncontrolled emissions; when abatement reaches 100, emissions have been driven to zero. Two equivalent policies will move the economy to the efficient level of abatement: a tax on emissions at rate T or a permit policy with Q_p permits.

[Figure 1: Emission Taxes and Permits]

If tax T were placed on emissions, every source would clean up all emissions that could be abated at a marginal cost less than or equal to T, pushing the level of abatement to Q_a. If a permit policy were imposed, on the other hand, sources would be forced to clean up to Q_a because only Q_p emissions would be allowed. The policies have sharply different distributional effects, which we will discuss further below, but in either case the efficient level of abatement, Q_a, would be achieved.

Under uncertainty, however, the situation becomes more complicated. Weitzman (1974) showed that taxes and permits may not be equally efficient when marginal benefits and costs are uncertain, and that the relative slopes of the two curves determine which policy will be better. To see why this is so, suppose that marginal benefits are known and that marginal abatement costs are believed, *ex ante*, to be given by marginal abatement cost curve MC_1 in Figure 2, and that a permit policy is put in place with Q_p permits issued.

[Figure 2: A Permit Policy in the Absence of Uncertainty]

As long as MC_1 is correct, the policy will be efficient and the level of abatement will be Q_1^a. The price of a permit will rise to P_1, the marginal cost of the last unit abated. However, suppose that after the policy is implemented, marginal costs are discovered to be much higher than expected. The situation is shown in Figure 3, where MC_2 is the *ex post* marginal cost curve.

Under these circumstances, the efficient level of abatement would fall to Q_2^a. Since there are only Q_p permits, however, firms will be forced to abate to Q_1^a. The price of a permit would rise substantially, to P_3, and the costs of the additional abatement would exceed the benefits by shaded triangle "P" in the diagram.

[Figure 3: A Permit Policy with Unexpectedly High Costs]

The potential inefficiency of a permit system is not just a theoretical curiosity: it is intuitively understood by many participants in the climate change debate, even those who have little training in economics. A non-economist might sum up a permit system by describing it as a policy that "caps emissions at any cost". The language differs from what an economist would use but the point is the same.

In this example, a tax policy would have been much more efficient *ex post*. If a tax had been imposed equal to P_1, *ex post* the level of abatement would have been Q_3^a – slightly too low but with a much smaller welfare loss (triangle "T") than the permit policy. The advantage of a tax stems from the fact that the marginal cost curve is much steeper than the marginal benefit curve. The marginal benefit curve for greenhouse gas abatement is very flat because temperature change is determined by the overall stock of pollutants in the atmosphere, which is much larger than annual emissions because carbon dioxide and other greenhouse gases remain in the atmosphere for many years.[14] The damage done by a ton of emissions changes only very slowly at the margin.[15]

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[14] The atmospheric lifetime of a greenhouse gas is the length of time a unit of it will remain in the atmosphere before being removed by natural processes. The atmospheric lifetimes of greenhouse gases can be very long: up to 200 years for carbon dioxide, 114 years for nitrous oxide, 45-260 years for chlorofluorocarbons, and up to 50,000 years for perfluoromethane (CF_4). For details, see IPCC (2001).

[15] For a more discussion of the benefits of abating emissions of stock pollutants, see Newell and Pizer (1998).

Although a tax would be more efficient than a permit system for controlling greenhouse gas emissions, it would have such large distributional effects that there is very little chance one would be enacted. The tax would induce firms to do the efficient amount of abatement but it would also require them to pay the tax on all of their remaining emissions, as illustrated in Figure 4.

[Figure 4: Inframarginal Transfers under a Tax Policy]

This transfer can be very large: if the efficient level of abatement is 20 per cent of uncontrolled emissions, firms will end up paying the tax on the remaining 80 per cent. To put that in context, if marginal abatement costs are linear, the tax rate is T and emissions are initially Q, the amount spent on abatement would be $0.2QT/2$, while the tax revenue will be $0.8QT$, eight times the size of the abatement costs. The ratio is even higher if abatement costs are convex. Transfers of this magnitude make a tax policy politically impossible.

Although permits and taxes both have serious economic and political disadvantages when used alone, those problems can be overcome by a hybrid policy that combines the best elements of both.[16] For efficiency, the hybrid should act like an emissions tax at the margin: it should provide incentives for abatement of all emissions that can be cleaned up at low cost while also allowing flexibility in total abatement if costs turn out to be high. For political viability, the hybrid should avoid unnecessarily large transfers and have the distributional flexibility of a permit system.

One policy that has all of these features is a modified permit system in which a fixed number of tradable, long-term emissions permits is supplemented by an elastic supply of short-term permits good only for one year. Each country participating in the policy would be allowed

[16] A hybrid policy was first proposed by Roberts and Spence (1976).

to distribute a specified number of long-term emissions, possibly an amount equal to the country's 1990 emissions. The permits could be leased or traded without restriction and each one would allow the holder to emit one ton of carbon per year. We will refer to these as "perpetual" permits, although in principle they permits could have long but finite lives. The permits could be given away, auctioned, or distributed in any other way the government of each country saw fit. Once distributed, the permits could be bought or sold among firms, or even bought and retired by environmental groups. In addition, each government would also be allowed to sell additional short-term permits for a specified fee, say U.S. $10.[17] Firms within a country would be required to have a total number of emissions permits, in any mixture of long and short term permits, equal to the amount of emissions they produce in a year. In order to comply, firms without enough permits could buy or lease perpetual permits from other firms, or they could buy annual permits from the government for the stated fee.

To see how the policy would work, consider the supply of permits available for use in any given year. On one hand, there will be an inelastic supply of Q_T perpetual permits for lease, where Q_T is the number of such permits outstanding. This is shown in Figure 5 by vertical line S_P. On the other hand, there will also be an elastic supply of annual permits available from the government at price P_T, which was specified in the policy. This is shown by horizontal line S_A in the figure. The total supply of permits is the horizontal sum of S_P and S_A, which is shown by the dark line in the figure.

[Figure 5: Supply of Each Type of Permit for Use in a Given Year]

The demand for permits will be determined by the marginal cost of abating emissions, as shown in Figure 6. The left panel shows two hypothetical marginal cost curves for abatement: a

[17] Ten dollars per ton of carbon is equivalent to a tax of $6.50 per ton of coal or $1.40 per barrel of crude oil.

low cost curve, MC_1, and a higher cost curve, MC_2. The right panel shows the corresponding demands for permits: D_1 and D_2. If costs are relatively low, as shown by MC_1, a given permit price P will induce Q_1^a units of abatement since those units can be eliminated for less than the price of a permit. As a result, firms will demand Q_1^p permits to cover their remaining emissions. If costs are relatively high, as shown by MC_2, firms will abate only Q_2^a units and will demand a larger number of permits. Thus, a flat marginal abatement cost curve implies a flat permit demand curve and a steep abatement cost curve implies a steep permit demand curve that is relatively far from the origin.

[Figure 6: Abatement Costs and the Demand for Permits]

Figure 7 shows two possible market equilibria that could result from combining the supply and demand curves for permits. If abatement costs turn out to be relatively low, permit demand will be low as well, as shown by curve D_1 in the diagram. In this case, the equilibrium permit price would be P_1, which is below the price of an annual permit, P_T. Only perpetual permits would be supplied and emissions would be reduced to Q_T. If abatement costs turn out to be high, however, permit demand will be given by a curve like D_2 instead. In that case, the price of a permit would be driven up to P_T and annual permits would begin to be sold. The final equilibrium price would be P_T and the total number of permits demanded would be Q_2. Of the total, Q_T would be perpetual permits and Q_2-Q_T would be annual permits. The important thing to notice is that no matter how high the marginal costs turn out to be, the price of a permit would be capped at P_T.

[Figure 7: Market Equilibria in Low and High Cost Cases]

Thus, the hybrid has the key advantages of both tax and permit policies: it behaves like a tax policy at the margin, which is essential given the deep uncertainties inherent in climate change policy. Firms would have an incentive to reduce emissions whenever they could do so for less than P_T per ton. Because the total supply of permits would not be fixed, the policy would not guarantee precisely how much abatement will be done. Because it is a market-based instrument, however, it would ensure that any abatement would be done at minimum cost. In fact, unless marginal costs of abatement are very low the pattern of abatement will be efficient across countries, as well as within each country. In particular, marginal abatement costs will be equalized in all countries where the price of a permit rises to P_T. Finally, the policy gives appropriate dynamic incentives: as long as the permit price is greater than zero, firms have an incentive to investigate new methods or technologies to reduce emissions further.

Although it has the efficiency advantages of an emissions tax, the hybrid policy does not have a tax's distributional liabilities. In particular, the block of perpetual permits gives the policy the distributional flexibility of a permit system and avoids the large transfers associated with a pure emissions tax. Moreover, any transfers that do occur are largely between firms or between firms and households, rather than between the private sector and the government. The policy also minimizes transfers across borders, avoiding the distributional issues discussed in the previous section.

The hybrid policy would also give governments a built-in incentives for monitoring and enforcement. The revenue raised through fees would be available for a variety of purposes: to reduce budget deficits, lower personal income taxes, or shore up social insurance programs. This would give governments enough incentive to enforce the policy that little or no international monitoring would be needed. In addition, firms will have an incentive to monitor each other because any cheating by one firm would put its competitors at a disadvantage and would also affect the value of permits held by other firms.

Another benefit of this policy is that it would also provide valuable information about the true marginal abatement cost curve. There is much debate about how easily emissions might be reduced: many economists believe that it will be quite costly, but others argue that emissions can be reduced substantially at low cost. A hybrid policy would do a lot to show which group is right.

The hybrid policy would also be flexible and decentralized. The price charged for annual permits could be adjusted as needed when better information became available on the seriousness of climate change and the cost of reducing emissions. Equally important, it would be easy to add countries to the system over time: those interested in joining would only have to adopt the policy domestically and no international negotiations would be required. That flexibility is crucial, because it is clear from the history of climate negotiations that only a few countries would now be willing to implement a significant global warming treaty in the near future. Furthermore, countries could withdraw from the system without debasing the value of the permits in those countries that continued to participate. Under a pure system of internationally tradable permits, the addition or withdrawal of any country could cause large swings in the price of permits.

Finally, an additional benefit is that the policy would be very transparent: to firms it would look like an unusually flexible form of grandfathering.

Overall, a hybrid policy is the most efficient and practical approach to climate change. It is politically realistic because it limits the cost of compliance and does not require governments to commit themselves to achieving a given target at any cost. It is more credible than a pure permit policy because it is not so draconian that countries will be tempted to renege, and because the revenue from selling permits will give governments an incentive to enforce it. Moreover, because it contains a built-in mechanism for limiting economic costs, the risk of setting emissions targets in the face of such great uncertainty about climate change is limited. This would remove the single most important obstacle to reaching a realistic international climate policy.[18]

Where Are We Now?

International negotiations on climate change policy began in earnest in 1992 at the Rio Earth Summit organized by the United Nations. The result of the summit was the United Nations Framework Convention on Climate Change (UNFCCC), which was signed and ratified by most of the countries in the world. The goal of the UNFCCC was to stabilize emissions of greenhouse gases at 1990 levels by the year 2000 through voluntary measures taken by individual countries.

In the intervening decade, few substantive policies have been implemented and global emissions of greenhouse gases have risen considerably. From that perspective, the UNFCCC has failed to achieve its goal. However, the Convention's real contribution was to set up a mechanism under which negotiations could continue as periodic "Conference of the Parties" (COP) meetings. The process of negotiations has been intense and is summarized Table 4.

A vast amount of effort, and most of the COP meetings, has been expended to try to implement a "targets and timetables" approach to climate change policy yet the outcome of these negotiations has been failure, which was entirely predictable given the uncertainties discussed above.

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[18] For more information about a hybrid approach to climate change policy, see McKibbin and Wilcoxen (1997a) and (1997b). This approach has also been endorsed by Kopp, Morgenstern and Pizer (1997) and Victor (2001).

This approach was crystallized in the Kyoto Protocol, which was negotiated in Kyoto in December 1997. This Protocol set explicit targets for each country in Annex B of that Protocol (essentially industrialized economies and several of the former members of the USSR) to target reductions in emissions of carbon equivalence across 6 gases to 5.2% below 1990 emission levels by the period from 2008 to 2010. Six gases were included as well as accounting for sinks. Flexibility would in principle be allowed through a number of mechanisms including international emission permit trading, clean development mechanism (CDM), and joint implementation (JI). Surprisingly, these ideas were accepted by the parties to the Protocol without specifying the rules of the system. In particular, there was no negotiation over issues of compliance, how institutional structures would work nor how developing countries would be involved. Between COP3 in Kyoto and COP6 at the Hague there were arduous negotiations over the details of how the Kyoto Protocol would actually be implemented that ultimately lead to a stalemate at COP6.

The negotiations begun at COP6 in the Hague were concluded at a second COP6 meeting in Bonn in July 2001. The result was an agreement that does not include the United States and has weaker targets for each country (through larger sink allowances). The extent of relaxation of the targets is so large (primarily to encourage Japan and Canada to participate) that it is likely that the targets forming the basis of the Kyoto-Bonn agreement should be met with lower cost that those under the original Kyoto Protocol. Essentially the process has demonstrated that, despite all the problems with a fixed targets and timetables approach, countries might be willing to commit to a targets and timetables approach as long as the targets are defined away. It is now possible that Europe and other key countries apart from the United States might ratify the latest form of the Kyoto Protocol. For entry into force the Kyoto Protocol requires countries accounting for 55% of emissions to ratify. This would require ratification by both Japan and Canada, and thus even the latest agreement is still highly uncertain.

Table 3: Chronology of Key International Negotiations on Climate Change

Meeting	Dates	Key Points
The Rio Earth Summit, Brazil	June 1992	United Nations Framework Convention on Climate Change (UNFCCC) signed by 153 countries. This is a legal framework to a non-binding aim of reducing atmospheric concentrations of greenhouse gases so as to achieve the goal of "preventing dangerous anthropogenic interference with the Earth's climate system". The goal was to stabilize emissions of greenhouse gases at 1990 levels by the year 2000. Established the Intergovernmental Panel on Climate Change (IPCCC) to assess scientific evidence related to climate change and actions. Ratified by the US in October 1992. Entered into force on March 24, 1994.
Conference of the Parties (COP) to the UNFCCC:		
COP-1 The Berlin Mandate	1995	Ministerial Declaration Adopted. Established a 2 year Analytical and Assessment Phase to negotiate a comprehensive set of options for countries to take actions. Industrial countries included in Annex I to the UNFCCC of countries to take action. Non-Annex I countries (developing countries) would be exempt from any future actions.
COP-2 Geneva, Switzerland	July 1996	Ministerial Declaration adopted. Accepted that climate change was a problem as argued by the IPCC; rejected uniform harmonized policies in favor of flexibility; and called for legally binding mid term targets. This opened door to international regulatory protocol.
COP-3 The Kyoto Protocol (KP), Kyoto, Japan	December 1997	Most industrial countries and some central European countries (as set out in Annex B of the Protocol) agreed to legally binding targets of on average 6%-8% below 1990 levels between the years of 2008 and 2012 (the first budget period). The design of how this would be done, and questions of measurement, compliance, enforcement etc were left for future negotiations.
COP-4 Buenos Aires, Argentina	November	Parties adopted a 2-year plan of action to design

	1998	mechanisms for implementing the KP. Issues discussed included financial transfers and clean development mechanism (CDM) for developing country participation. Also discussed issues for incorporating "carbon sinks".
COP-5 Bonn, Germany	Oct-Nov 1999	Design of technical and political mechanisms – Joint implementation (JI), Clean Development Mechanism (CDM) and criteria for project eligibility. Discussion of legally binding consequences for non-compliance of parties.
COP-6 The Hague, Netherlands	November 2000	Negotiations ended without progress. Many unresolved issues on compliance, sinks, and use of flexibility mechanisms. EU attempted to impose limits on flexibility mechanisms.
COP-6bis Bonn, Germany	July 2001	The continuation of COP6 because of stalemate at The Hague. President Bush declared in March 2001 that the US would not participate in KP. Annex B countries agreed to proceed without the US, after giving away large sink adjustments to Japan and Canada. With Russian "hot air" and the larger allowance for sinks, the effective targets for the first budget period were substantially reduced and may no longer be a constraint. Many unresolved issued of enforcement, mechanism etc. and still enormous complications in the KP but the issue of high costs was diminished.
COP-7 Marrakesh,	October 2001	?

Although four years and five COP meetings have been devoted to the Protocol, there remain a number of fundamental problems that will likely derail the Protocol, even with the recent Bonn adjustments.The reason is simple: the fundamental approach of Kyoto Protocol, setting "targets and timetables" for emissions reductions, is seriously flawed. It fails to address uncertainty and the distributional issues crucial to climate change policy, and we will briefly outline the key problems below.

First, the Kyoto Protocol would force emissions back to 1990 levels and hold them there without regard to the costs and benefits of doing so. As noted above, studies to date provide little justification for that target, instead suggesting that the costs exceed the benefits, perhaps substantially.

Second, countries could take a variety of domestic actions but the principal international policy instrument would be a system of internationally-tradable emissions permits. International permit trading, in addition to being inefficient given the nature of the uncertainties of climate change, would likely generate large transfers of wealth between countries. Supporters of a permit system regard this as an advantage because it would allow developed countries to compensate developing countries for reducing their emissions. However, the size of the transfers makes it unlikely the treaty would be ratified. Consider the following rough calculation. In 1990 the United States emitted about 1,340 million tons of carbon in the form of carbon dioxide. Carbon emissions are expected to grow over time, so suppose that by 2010 the United States ended up needing to import permits equal to about 20 percent of 1990 emissions, or about 268 million tons. There is enormous uncertainty about what the price of an international carbon permit might be, but $100 a ton is well within the range of estimates and some studies have projected prices of $200 or more. In this scenario, the permit system would add $27 billion to $54 billion to the U.S. trade deficit every year. To put this in context, the entire U.S. trade deficit in 1996 was $114 billion.

It is also worth comparing it to the often-controversial U.S. foreign aid budget. Supporters of the policy argue that emissions reductions will be cheapest in developing countries, developing countries could be large sellers of permits on the international market. The value of permits would dwarf the U.S. foreign aid budget, which is now about $17 billion. Transfers of wealth of this magnitude guarantee the treaty would never be implemented regardless of its economic merits.

A third problem with the Kyoto Protocol is that it would likely put enormous stress on the world trade system. The balance of trade for a developed country importing permits would deteriorate substantially. Although trading would equalize marginal abatement costs across countries, achieving that efficiency would be likely to substantial volatility in exchange rates and distortions in the world trade system.

Equally serious problems might be created for developing countries. Massive exports of permits would lead to exchange rate appreciation and a decline or collapse in exports other than permits. Also, the permit revenue comes with strings attached: much of it would have to be invested in improved energy technology in order to reduce emissions and free up the permits in the first place. This is unlikely to be an ideal strategy for long-term economic development and would make the policy unattractive to developing countries.

In fact, developing countries have been so unenthusiastic about international permit trading that the Kyoto Protocol actually stops short of setting up a worldwide system of permits. Instead it would set up a system of trading among developed countries and the former Soviet Union ("Annex B Countries" in the language of the negotiations). However, this is a compromise that essentially dilutes the main reason for having internationally tradable permits in the first place: the potential gain from trade in emissions rights between industrialized and developing countries. Permit trading would do little to lower abatement costs when the participating countries have fairly similar technology.

Finally, another problem with the Kyoto Protocol, acknowledged even by its supporters, is that no individual government would have any incentive to police the agreement. It is easy to see why this is so: monitoring polluters is expensive, and punishing violators imposes costs on domestic residents in exchange for benefits that will accrue largely to foreigners. There would be a strong temptation for governments to look the other way when firms were exceeding their emissions permits. For the treaty to be viable, however, each participating country would need to be confident that all of the other participants were enforcing it. This would require an elaborate and expensive international mechanism for monitoring and enforcement. Compliance is one of the key obstacles in negotiations

Ironically, the Kyoto Protocol (especially post-Bonn) would not even achieve the original UNFCCC goal of stabilizing emissions. Britain, Germany, and especially Russia are all already below their 1990 emission levels and would be able to sell their unused permits abroad. In that case the permit system would really amount to nothing more than an elaborate accounting mechanism for counting increases in emissions in countries like the United States and other emitters in Europe against the 1990 allocation for Russia. There would be little or no overall reduction.

All in all, the Kyoto Protocol is not politically viable in the United States and many other developed countries; might distort or compromise the world trade system; would be unattractive to developing countries; and would be difficult to monitor and enforce. It is an impractical policy focused on achieving an unrealistic and inappropriate goal.

There is now much uncertainty about the state of climate change negotiations. The Kyoto-Bonn agreement has relaxed the ambitious targets of the original Kyoto Protocol substantially. Lowering of expected costs of the Protocol duing in the first commitment period might cause more countries to ratify the agreement. Yet the fundamental problems with Protocol will remain. Therefore it is quite possible that in future periods, the costs of participation exceed the benefits and countries might then withdraw. Thus it is now increasingly possible that an unstable system could develop among a subgroup of countries accounting for a diminishing share of global emissions. This would set back the ability to implement a sensible policy for a long period.

Conclusion

Climate change poses two challenges for policy makers: it is fraught with enormous uncertainties that are unlikely to be resolved for decades; and the distributional effects of any policy will be critical to its prospects for ratification and need to be taken into account during the policy's design. Economic theory, however, is up to these challenges and provides exactly the analytical tools needed. The appropriate policy is a hybrid combining the best features of an emissions tax with the distributional advantages of a permit system. The hybrid policy would be efficient, politically realistic and could be implemented in a variety of countries with enough flexibility to be ratified within each country

Unfortunately, international negotiations to date have produced a very different policy, the Kyoto Protocol, which is deeply flawed. The Protocol never had any real chance of ratification by the U.S. Senate and has now been rejected by the Bush Administration. As a result, however, a rare window of opportunity has opened in the policy process for economists to present a better alternative.

References

Diamond, Peter A. and Jerry A. Hausman (1994), “Contingent Valuation: Is Some Number better than No Number?” *The Journal of Economic Perspectives*, 8(4), pp. 45-64.

Kopp, Raymond, Richard Morgenstern and William A. Pizer (1997), “Something for Everyone: A Climate Policy that Both Environmentalists and Industry Can Live With,” *Weathervane*, Resources for the Future, Washington, September 29.

Newell, Richard G. and William A. Pizer (1998), “Regulating Stock Externalities Under Uncertainty,” Discussion Paper 99-10, Resources for the Future, Washington.

Energy Journal (1999), “Special Issue: The Costs of the Kyoto Protocol: A Multi-Model Evaluation”.

Intergovernmental Panel on Climate Change (2001), *Third Assessment Report*, Cambridge: Cambridge University Press.

Nordhaus, William D. (1991), “The Cost of Slowing Climate Change: A Survey,” *The Energy Journal*, 12(1).

Nordhaus, William D. (1993), “Reflections on the Economics of Climate Change,” *Journal of Economic Perspectives*, 7(4).

McKibbin W. and P. Wilcoxen (1997a) “A Better Way to Slow Global Climate Change” *Brookings Policy Brief*, no. 17, June, The Brookings Institution, Washington.

McKibbin W. and P. Wilcoxen (1997b) “Salvaging the Kyoto Climate Change Negotiations” *Brookings Policy Brief*, no. 27, November, The Brookings Institution, Washington.

National Climate Data Center (1999), “Climate of 1998 – Annual Review”, US National Oceanic and Atmospheric Administration.

Roberts, Marc J., and A. Michael Spence (1976), "Effluent Charges and Licenses under Uncertainty," *Journal of Public Economics*, 5, 193-208.

Victor, David (2001), *The Collapse of the Kyoto Protocol and the Struggle to Control Global Warming*, Council on Foreign Relations.

Weitzman, Martin L. (1974), "Prices vs. Quantities," *Review of Economic Studies*, 41, 477-91.

Figure 1: Emission Taxes and Permits

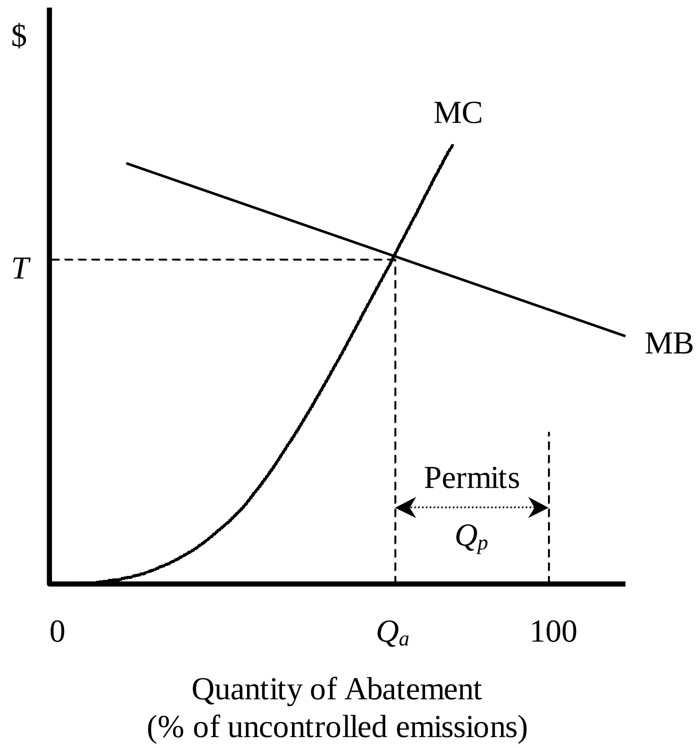

Figure 2: A Permit Policy in the Absence of Uncertainty

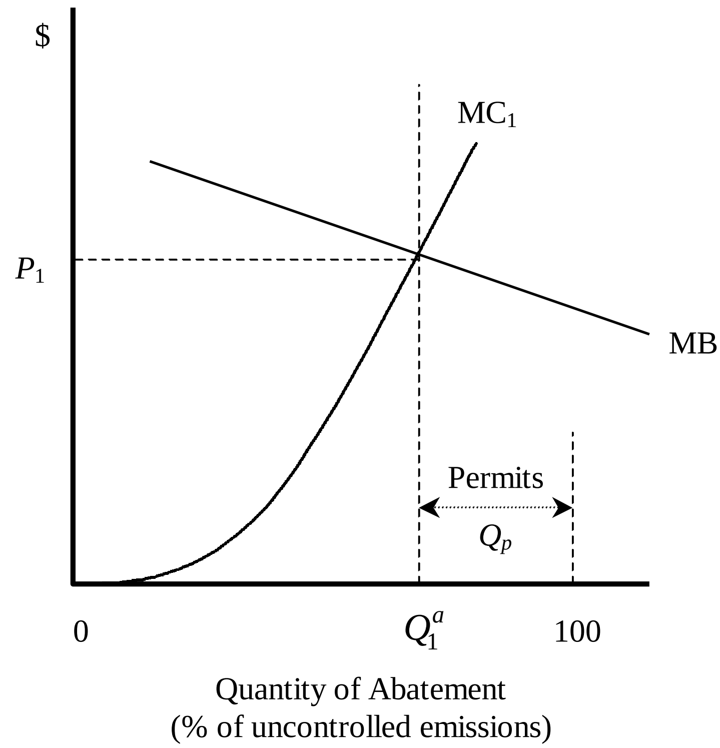

Figure 3: A Permit Policy with Unexpectedly High Costs

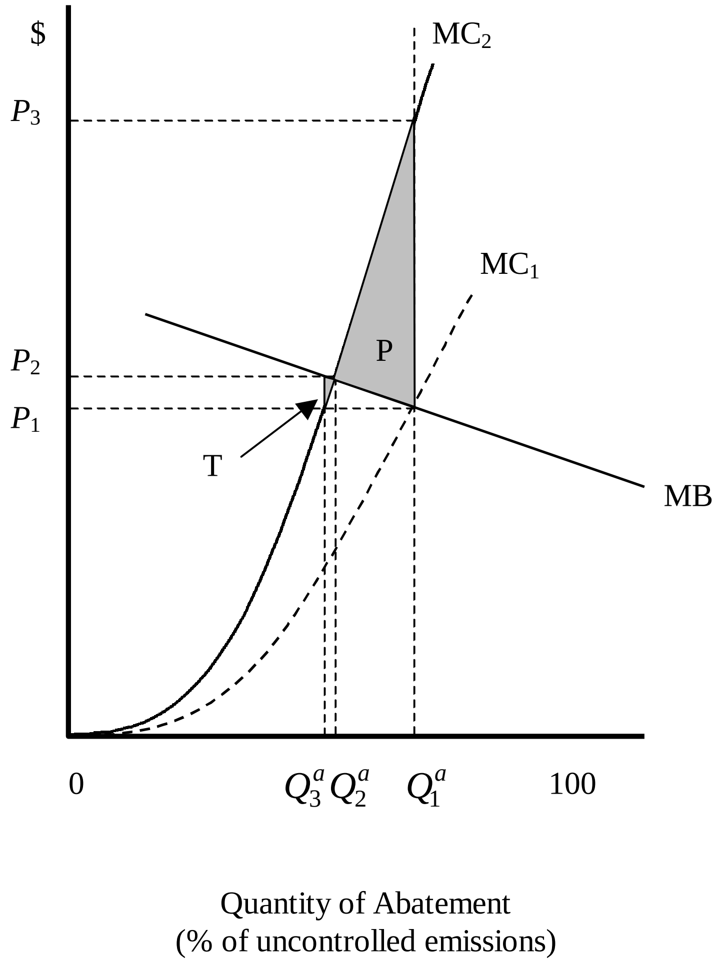

Figure 4: Inframarginal Transfers under a Tax Policy

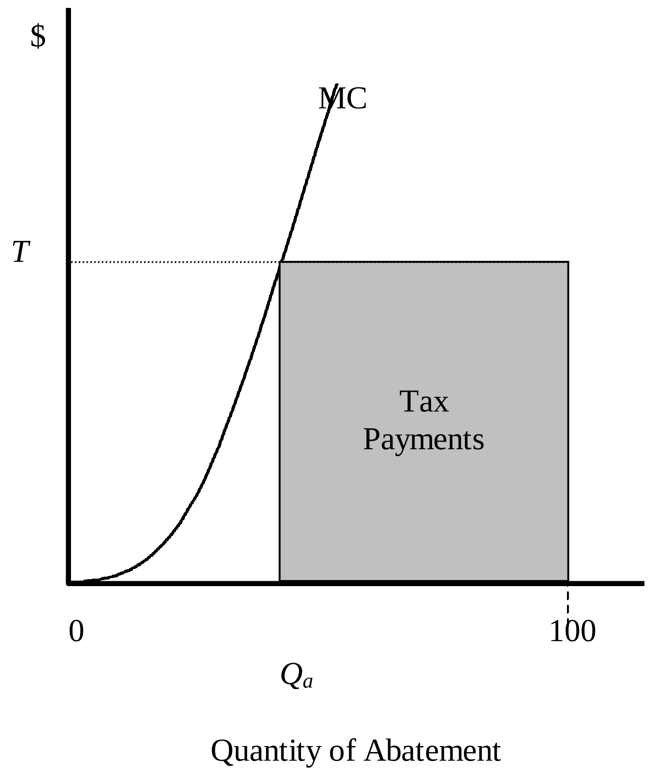

Figure 5: Supply of Each Type of Permit for Use in a Given Year

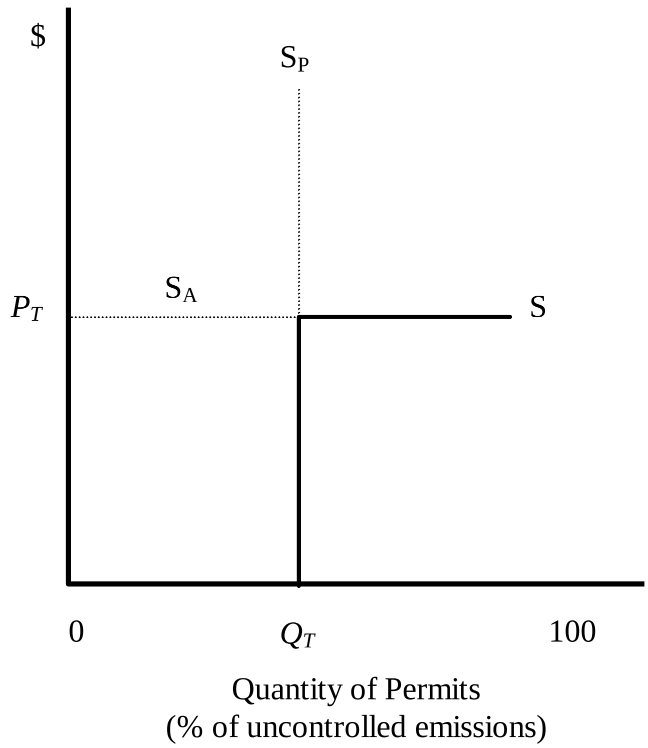

Figure 6: Abatement Costs and the Demand for Permits

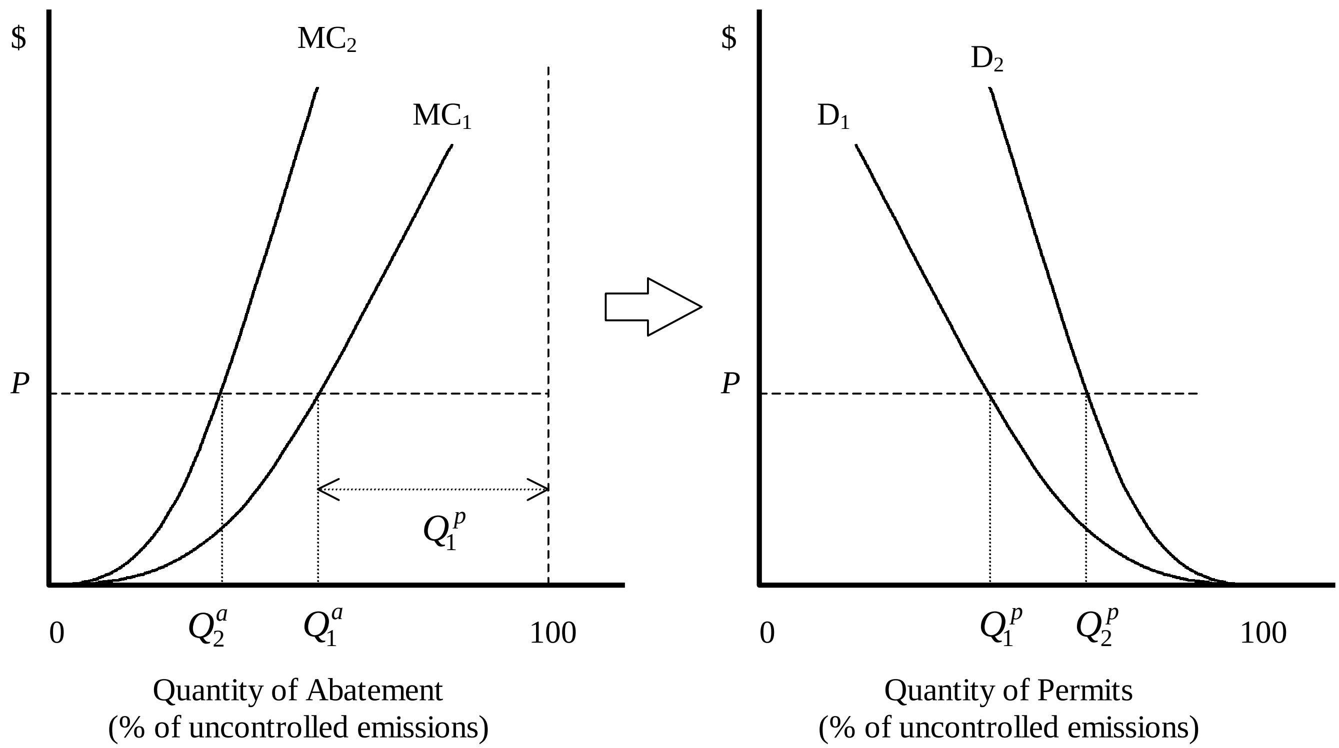

Figure 7: Market Equilibria in Low and High Cost Cases