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The Role of Economics in Climate Change Policy

Warwick J. McKibbin and Peter J. Wilcoxen

Many policy problems have frustratingly long histories of inefficient regulation that can be difficult or impossible to reverse, even where large efficiency gains might be had from doing so. Climate change is an exception, however, because little real action has been undertaken to date. It presents an unusual opportunity for an efficient economic policy to be employed right from the beginning. However, the opportunity could easily be lost. Ongoing negotiations conducted under the auspices of the United Nations Framework Convention on Climate Change have so far produced the Kyoto Protocol, a deeply flawed agreement that manages to be both economically inefficient and politically impractical.

In this article, we examine the key economic characteristics of climate change and argue that economic theory provides good guidance on the design of an efficient and politically realistic policy. Because climate change involves vast uncertainties and has potentially enormous distributional effects, neither of the standard market-based environmental policy instruments is a viable approach: a tradable permit system would be inefficient, and an emissions tax would be politically unrealistic. However, a hybrid policy, combining the best features of the two, would be an efficient and practical approach. We then compare our hybrid proposal to the Kyoto Protocol and argue that it overcomes the Protocol's shortcomings.

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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. 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 the atmosphere held no carbon dioxide, 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 known as the "greenhouse effect," because it traps energy near the Earth's surface in a manner somewhat analogous to the way glass keeps a greenhouse warm. Carbon dioxide and other gases contributing to this effect are called "greenhouse gases."

The second undisputed fact is that the concentration of many greenhouse gases has been increasing rapidly due to human activity. Every year, fossil fuel use adds about six billion metric tons of carbon—in the form of carbon dioxide—to the atmosphere. As shown in Table 1, emissions are largest in industrialized countries, but growing most rapidly in the developing world (Energy Information Administration, 1999). Once emitted, carbon dioxide remains in the atmosphere for as long as 200 years. As a result, the atmospheric concentration of carbon dioxide—and hence its effect on temperature—reflects the stock of accumulated emissions over decades. Studies of ice cores from Antarctica show that carbon dioxide levels varied between 270 and 290 parts per million for thousands of years before the beginning of the Industrial Revolution.[1] By 1998, however, the concentration had risen to 365 parts per million, an increase of 30 percent.

Human activity has increased the concentration of other greenhouse gases as well. The concentration of methane—emitted as a byproduct of agriculture, natural gas production and landfills—has risen by 150 percent: from 700 parts per billion to 1,745 parts per billion in 1998. The concentration of nitrous oxide has also risen over the same time frame, although by a more modest 17 percent. Finally, chlorofluorocarbons comprise only a small fraction of the atmosphere, but they are entirely the result of human activity and are especially effective at trapping infrared

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[1] The scientific literature on the causes of climate change, its potential effects on natural ecosystems and human populations, and on policies that might be used in response has been exhaustively surveyed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC was created in 1988 under the joint sponsorship of the World Meteorological Organization and the United Nations Environment Programme. To date, it has conduced three assessments of the literature, each involving hundreds of natural and social scientists from around the world. These figures, and others in the paper that are not specifically attributed to another source, are drawn from the IPCC's most recent study, the *Third Assessment Report,* which was completed in 2001.

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Table 1
Recent Carbon Emissions by Region and Country
(millions of metric tons of carbon)

Region	*Carbon (MMT)* *1990*	*1999*	*Percentage of 1999 Total*	*Increase from 1990 to 1999*
North America	1567	1772	29%	13%
Canada	128	151	2%	18%
Mexico	84	101	2%	20%
United States	1355	1520	25%	12%
Central and South America	192	267	4%	39%
Brazil	63	89	1%	41%
Other	129	178	3%	38%
Western Europe	1006	1015	17%	1%
Germany	271	230	4%	−15%
United Kingdom	164	152	2%	−7%
Other	571	633	10%	11%
Eastern Europe and the Former USSR	1298	789	13%	−39%
Russia	647	400	7%	−38%
Other	651	389	6%	−40%
Middle East	203	287	5%	41%
Africa	198	237	4%	20%
Far East and Oceania	1410	1776	29%	26%
Australia	72	94	2%	31%
China	617	669	11%	8%
India	156	243	4%	56%
Japan	269	307	5%	14%
Other	296	463	8%	56%
World Total	5873	6143	100%	5%

energy. Together, the increased concentrations of methane, nitrous oxide and chlorofluorocarbons contribute about two-thirds as much heat-trapping capacity to the atmosphere as the increase in carbon dioxide.

Beyond these two points, controversy arises. Although greenhouse gases can trap energy and make the atmosphere warmer, and the concentration of those gases has been increasing, it is far from 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 such warming 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 a feedback cycle that exacerbates any temperature increase caused by carbon

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dioxide. On the other hand, a given increase in atmospheric capacity to hold water vapor does not necessarily imply an equal increase in water vapor, since much of the atmosphere is not saturated.

A closely related uncertainty is the role of clouds. Clouds reflect ultraviolet radiation, thus reducing the amount of solar radiation reaching the ground, so an increase in cloud cover could tend to reduce the greenhouse effect. At the same time, clouds 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 to attenuate temperature changes from other sources.

Another problem is determining how quickly ocean temperatures will respond to global warming. Water has a high capacity for holding heat, 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. However, 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. These tiny particles or droplets reflect a portion of incoming solar radiation, which tends to reduce climate change, but they also absorb infrared, which tends to increase it. The concentration of aerosols in the atmosphere seems to be increasing, and this increase may have partially offset the increase in carbon dioxide during the last century (Intergovernmental Panel on Climate Change, 2001c).

These uncertainties are very difficult to resolve, but scientists have nonetheless attempted to estimate the effect of greenhouse gases on climate. The earliest effort was in 1895, by a Swedish chemist named Svante Arrhenius who used a very simple model with limited data to show that the presence of carbon dioxide in the atmosphere raises the Earth's surface temperature substantially. 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 is about 14°C (57°F), and a change of this magnitude would give Los Angeles a climate roughly like that of Nome, Alaska. Arrhenius also calculated that doubling the concentra-

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tion of carbon dioxide in the atmosphere from preindustrial levels—which on current projections is likely to happen sometime between 2050 and 2100—would raise global average temperatures by 4 to 6°C.

Today, elaborate climate models that capture many more physical and chemical interactions suggest that doubling carbon dioxide concentrations would raise global average temperatures by 1.5 to 4.5°C. Although the magnitude of warming remains uncertain, there is no serious scientific disagreement about the underlying problem: no climate models predict zero warming, and no one seriously suggests that greenhouse gas concentrations can continue to increase without eventually producing some degree of warming.

Estimating the impact of past greenhouse gas emissions on current global temperatures has proven equally difficult. 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 quite hard to prove that global warming has begun. Normal variations in global temperatures are large, and it is very difficult to tell whether actual increases in temperature are outside the usual range and, thus, hard to tell how much warming may have occurred.

What's more, temperature measurements themselves can be suspect, in part because over the years, people have measured temperatures with different kinds of instruments, at different locations and even at different altitudes. One 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 (2001c) concluded that during the twentieth 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 to 90 percent probability. This conclusion is suggestive, but it would be a substantial overstatement of current scientific knowledge to conclude that anthropogenic warming has been measured accurately in historical data. At the same time, the underlying problems of measurement and causality 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 by the Intergovernmental Panel on Climate Change (2001c) finds that the concentration of carbon dioxide in the atmosphere in 2100 is likely to exceed preindustrial levels by 75 to 350 percent. This enormous range of uncertainty is very difficult to resolve. Predicting the emissions of carbon dioxide depends heavily on many factors—population growth, technical change, income growth and energy prices, among

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other things—none of which are easy to predict themselves. Other greenhouse gas concentrations are likely to increase as well, although by amounts that are equally difficult to predict. Predictions of global average surface temperatures in 2100 range from increases of 1.4°C to 5.8°C above 1990, and even that large range does not include all identifiable uncertainties. Given the complexity of the processes involved, scientists will probably be unable to reduce this uncertainty for decades.

Moreover, climatology is only one of several sources of uncertainty that are important for climate change policy. Even if temperature changes could be predicted perfectly, many of the physical and ecological consequences of temperature change are less well understood than climatology.

Some 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 increase 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. 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 three meters—are now thought to be very unlikely before 2100.

Table 2 gives a brief summary of other possible effects of global warming on the climate. Where possible, the relative certainty of each effect is indicated following the terminology of the Intergovernmental Panel on Climate Change (2001c): "very likely" means a 90 to 99 percent chance, "likely" means a 66 to 90 percent chance, "medium" means a 33 to 66 percent chance and "unlikely" means a 10 to 33 percent chance. These levels of certainty roughly indicate the amount of agreement among climatologists and are not formal probability estimates. Moreover, these effects on climate change will vary by region.

These changes in climate are likely to produce a variety of effects on ecosystems and human activities, as summarized in Table 3. 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. For example, the agricultural damage done by climate change depends on the costs of adapting crops and farming methods, which vary across regions and are largely unknown. Moreover, climate change can actually be good for agriculture in certain circumstances: some crops benefit more from higher carbon dioxide levels than they are hurt by temperature and precipitation changes. Most uncertain of all are the values to assign 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

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Table 2
Possible Climatic Consequences of Higher Global Temperatures

Extreme weather events	Increase in frequency of heat waves; higher risk of summer droughts over continental areas at midlatitudes; more intense precipitation. (Likely to very likely)
Tropical storm intensity	Higher peak wind speeds and more intense precipitation in cyclones, hurricanes and typhoons. (Likely)
Patterns of precipitation	Increase in average global evaporation and precipitation, but with substantial regional variability.
Midlatitude storm intensity	Changes cannot be determined from current climate models.
Atlantic thermohaline circulation	Differences in water temperature and salinity produce the Gulf Stream and other currents that bring warm surface water to the North Atlantic. Without these currents, the climate in northern Europe would be significantly colder. Current climate models show that this circulation is likely to weaken over the next 100 years, but not enough to cause a negative net temperature change in Europe: the increase due to global warming exceeds the reduction due to changes in currents.
Decomposition of methane hydrates	Deep ocean sediments contain an enormous reservoir of methane in the form of frozen deposits called hydrates. If ocean temperatures warmed enough to allow these deposits to thaw, there would be a dramatic increase in atmospheric greenhouse gas concentrations. However, recent studies indicate that the temperature changes expected from global warming over at least the next 100 years will be too small to trigger such an event.

agree on the methodology to be used in these cases, much less on the estimates themselves.[2]

Overall, the Intergovernmental Panel on Climate Change (2001a) concludes with "medium confidence" (33 to 67 percent) that the aggregate market sector impacts of a small increase in global temperatures could be "plus or minus a few percent of world GDP." The effects tend to be small—or even positive—in developed countries. 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.[3]

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

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[2] The main method used to determine what people are willing to pay for environmental goods that they don't use directly is "contingent valuation," which involves estimating people's willingness to pay based on their answers to opinion surveys. However, contingent valuation has some serious problems: see Diamond and Hausman (1994) in this journal for a detailed critique.

[3] Aggregate GDP is far from ideal as a measure of welfare, especially when applied to something as heterogeneous as the world economy. We cite these figures to indicate the uncertainties involved in measuring the effects of climate change rather than to endorse GDP as a welfare measure. Other frameworks that incorporate equity, sustainability and development concerns are discussed in Intergovernmental Panel on Climate Change (2001b).

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Table 3
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 percent of Bangladesh and affect 5.5 million people; with a 100 cm rise, inundation increases to 21 percent 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 coastal storms will increase by 75 to 200 million.

Human health
Increased heat-related injuries and mortality and decreased 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 percent.

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)

the 1997 Kyoto Protocol (which will be discussed in detail below). The studies typically determine the marginal cost of reducing emissions by calculating the carbon tax—a tax levied on fossil fuels in proportion to their carbon content—that would be needed to drive emissions down to a specified level. A ton of coal contains 0.65 tons of carbon, so a $1 per ton carbon tax would translate into a tax of $0.65 per ton of coal; the same tax would add $0.14 to the price of a barrel of crude oil and $0.02 to the price of a thousand cubic feet of natural gas.

The results vary substantially across models. For example, the carbon tax needed in the United States to reduce greenhouse gas emissions to 93 percent of 1990 levels by 2010 (as would be required by the Kyoto Protocol) ranges from $94 to $400 (in 2000 U.S. dollars) per ton of carbon.[4] To put this in perspective, the tax

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[4] The figures in this paragraph are drawn from Energy Modeling Forum 16, a multimodel 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 Intergovernmental Panel on Climate Change (2001c).

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on a barrel of crude oil would be $13 to $55, which would raise the price of a $20 barrel of oil by 65 to 275 percent. The tax on a ton of coal would be $60 to $260, raising the price of a $22 ton of coal by 270 to 1,180 percent. The range of estimates for the carbon tax needed to reduce emissions in European OECD countries is even larger: $25 to $825 per ton of carbon.

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, like variation in estimates of the short-term price elasticity of demand for gasoline. 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 very far into the future.

In short, 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. Before presenting our version of a policy to address these uncertainties, however, it is important to discuss a second important attribute of climate change policy: distribution effects. Any serious climate change policy will need widespread participation over a long time. The key to assuring participation is to be realistic about distributional issues in the design of the policy.

A Hardheaded Look at Distributional Issues

Greenhouse gas emissions originate throughout the world, and most countries will eventually need to participate in any solution. A treaty that makes heavy demands on national sovereignty, or that requires large transfers of wealth from one part of the world to another, is unlikely to be ratified or, if ratified, is likely to be repudiated sooner or later. No international agency can coerce countries to comply with a climate change agreement they find significantly inconsistent with their national interest.

Unfortunately, much of the debate over the distributional aspects of climate change policy has focused on a different question: Which countries should be held responsible for reducing climate change? Some argue that industrialized countries are obligated to do the most to avoid climate change because their emissions have caused most of the increase in greenhouse gas concentrations to date. 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. Both of these positions are true, but neither is a realistic basis for designing a policy that sovereign nations will have to ratify and to implement.

In addition, an international agreement should be explicitly designed to make it easy for governments to address domestic distributional concerns in a flexible

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and transparent manner. For example, a policy involving tradable permits gives governments a distributional instrument—the initial allocation of permits—that would be absent under a pure emissions tax. Tradable permits would allow a government to provide "transition relief" easily and transparently to an industry by granting firms enough permits to cover a large share of their initial emissions. From the industry's point of view, the policy would be a flexible form of grandfathering. In contrast, if the international policy were a pure emissions tax, the compensation scheme would have to be a system of side payments, entirely separate from the treaty, that would be more difficult to negotiate at the domestic level and far less transparent internationally.

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 climate change is an "unproved theory"—and that 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 risks from global warming are so severe that substantial cuts should be made in greenhouse gas emissions immediately, regardless of the cost. Neither position is appropriate. On one hand, increasing the concentration of greenhouse gases in the atmosphere exposes the world to the risk of an adverse change in the climate, even though the distribution of that risk is poorly understood. Enough is known to justify reducing greenhouse gas emissions, particularly to preserve the option of avoiding an irreversible change in the climate. On the other hand, too little is known about the causes and consequences of climate change to justify a draconian cut in emissions. Given the uncertainties, a prudent approach would be to abate emissions where possible at modest cost.

Minimizing the cost of abating a given amount of greenhouse emissions requires that all sources clean up amounts that cause their marginal costs of abatement to be equated. To achieve this, the standard economic policy prescription would be 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, although the distributional effects of tax and emissions trading policies would be very different. Under uncertainty, however, the situation becomes more complicated. Weitzman (1974) showed that taxes and permits are *not* equivalent 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, consider a hypothetical air pollutant. The pollutant is dangerous only at high levels: it causes no damage at all when daily emissions are below 100 tons, but each ton emitted beyond that causes $10 worth of health

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problems. Emissions are currently 150 tons per day, so the marginal benefit of abatement would be \$10 (the damage avoided) for each of the first 50 tons eliminated. Beyond that point, however, the marginal benefit of abatement would drop to zero: emissions would be below the 100 ton threshold and no longer causing any damage. This is an example of a steep marginal benefit curve: at the threshold, marginal benefits go rapidly from \$10 to zero. Finally, suppose that the pollutant can be cleaned up with constant returns to scale—the marginal cost curve is flat—but the precise cost is uncertain: all that is known is that the cost of clean-up is less than \$10 per ton.

Given this information, the efficient amount of pollution is 100 tons. Above 100 tons, the damage of an additional ton is higher than the cost of abating it; below 100 tons, further reductions produce no additional benefit. In this situation, a permit policy would be far better than an emissions tax. By issuing permits for 100 tons of emissions, the government could be sure of achieving the efficient outcome: for any marginal cost below \$10, the permit system will keep emissions from exceeding the threshold. A tax, on the other hand, would be a terrible policy. Suppose the government imposed a \$5 tax and the marginal cost of abatement turned out to be \$6. In that case, firms would choose to pay the tax rather than do any abatement, and emissions would remain at 150 tons. If costs turned out to be low, say \$4, the situation would be no better: in that case, firms would clean up everything and emissions would drop to zero. This example captures the essence of the advantage permits have over taxes when marginal benefits are steep and marginal costs are flat: in that situation, it is important to get the quantity of emissions down to a threshold. A permit policy does exactly that.

In the opposite situation, when marginal costs are rising sharply and marginal benefits are flat, a tax would be a better policy. This case is shown graphically in Figure 1. The horizontal axis shows the quantity of abatement and is normalized so that complete elimination of the pollutant requires 100 units of abatement. The marginal benefit of abatement, *MB*, is flat, and the marginal cost of abatement is believed—at the time of regulation—to rise sharply, as shown by MC_1 in the left panel. Without regulation, firms would do no abatement, and the quantity on the horizontal axis would be zero. If the government imposes a permit policy, it can guarantee a certain level of abatement—say, Q_1^a. But if marginal costs are uncertain, Q_1^a may not turn out to be the efficient outcome. For example, suppose that marginal costs turn out to be higher than expected. That situation is shown in the right panel of Figure 1, where the true marginal cost curve is shown by MC_2. Because abatement is more expensive than expected, efficiency would require doing less of it: Q_2^a instead of Q_1^a. If firms were forced to abate to Q_1^a, the price of a permit would rise substantially, to P_3. The costs of the excess abatement would exceed the benefits by shaded triangle *D* in the diagram.

The potential inefficiency of a permit system is intuitively understood by many participants in the climate change debate. A noneconomist might sum up a permit

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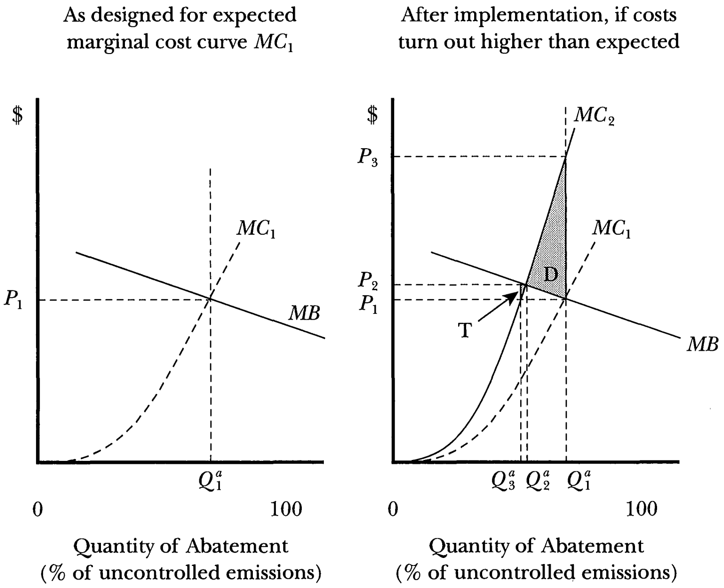
Figure 1
A Permit Policy Under Uncertainty



system by describing it as a policy that "caps emissions regardless of 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 a much wiser choice. Suppose that in the initial situation, with the low expected marginal cost curve, a tax had been imposed equal to P_1. Once firms discovered that the true marginal cost curve they faced was substantially higher than expected, the level of abatement would drop to Q_3^a—slightly too low, but with a much smaller welfare loss (triangle *T*) than the permit policy would have produced. The tax is more efficient because it more closely approximates the flat marginal benefit curve.

Applying this analysis to climate change suggests that a tax is likely to be far more efficient than a permit system. All evidence to date suggests that the marginal cost curve for reducing greenhouse gas emissions is very steep, at least for developed countries. At the same time, the nature of climate change indicates that the marginal benefit curve for reducing emissions will be very flat. The damages from climate change are caused by the overall stock of greenhouse gases in the atmosphere, which is the accumulation of many years of emissions. Greenhouse gases remain in the atmosphere for a long time: up to 200 years for carbon dioxide, 114 years for nitrous oxide, 45 to 260 years for chlorofluorocarbons and up to 50,000 years for perfluoromethane (CF_4). As a result, the marginal damage curve for emissions of a gas in any given year will be flat: the first ton and the last ton emitted in that year will have very similar effects on the atmospheric concentration of the

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gas and hence will cause very similar damages.[5] For example, any single year's emissions of carbon dioxide will be on the order of 1 percent of the excess carbon dioxide in the atmosphere. Within that 1 percent, the damages caused by a ton of emissions will be essentially constant.

Although a tax would be more efficient than a permit system for controlling greenhouse gas emissions (given flat marginal benefits, rising marginal costs and high levels of uncertainty), a tax has a major political liability: it would induce large transfers of income from firms to the government. In fact, firms would end up paying far more in taxes than they spent on reducing emissions. For example, suppose that a particular firm was initially emitting Q tons of carbon dioxide and that its efficient abatement (where the marginal cost of abatement equaled the marginal benefit) was 20 percent. Under an efficient tax, T, the firm would eliminate $0.2Q$ tons of emissions at a cost no larger than $0.2QT$ (the firm would never pay more to abate its emissions than it would save in taxes, and it might pay much less if the marginal cost of abating the initial units of pollution was quite low). However, the firm would have to pay taxes on its remaining emissions, and its tax bill would be $0.8QT$, at least four times what it spent on abatement. The political problem is not just that firms dislike paying taxes; rather, it is that the transfers would be so much larger than the abatement costs that they would completely dominate the political debate. A firm that might be willing to pay $1 million to reduce its emissions by 20 percent would almost certainly be hostile to a policy that required it to pay $1 million plus an additional $4 million in taxes. The problem is not unique to climate change and is probably the most important reason that Pigouvian taxes have rarely been used to control environmental problems.

Although marketable pollution permits and pollution taxes can have serious economic and political disadvantages when used alone, those problems can be mitigated by a hybrid policy that combines the best elements of both.[6] For efficiency, the hybrid policy should act like an emissions tax at the margin: it should provide incentives for abating 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 hybrid policy with these features would combine a fixed number of tradable, long-term emissions permits with an elastic supply of short-term permits, good only for one year. Each country participating in the policy would be allowed to distribute a specified number of long-term emissions permits, possibly an amount equal to the country's 1990 emissions. The permits could be bought, sold or leased 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

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

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

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principle, they 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 traded among firms or bought and retired by environmental groups. In addition, each government would be allowed to sell additional short-term permits for a specified fee, say for \$10 per ton of carbon. To put the fee in perspective, \$10 dollars per ton of carbon is equivalent to a tax of \$6.50 per ton of coal and \$1.40 per barrel of crude oil; other things equal, the price of a \$22 ton of coal would rise by about 30 percent, and the price of a \$20 barrel of oil would rise by 7 percent. 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.

To see how the policy would work, consider the supply of permits available for use in any given year. 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 2 by vertical line S_P. There will also be an elastic supply of annual permits available from the government at price P_T. 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 right-turn supply curve in the figure.

The demand for permits will be determined by the marginal cost of abating emissions. Figure 2 shows two possible market equilibria that could result from combining the supply curve for permits with two possible demand curves. If abatement costs turn out to be relatively low, so that permit demand is given by curve D_1, the equilibrium permit price would be P_1, which is below the price of an annual permit, P_T. In this case, only perpetual permits would be supplied, and emissions would be reduced to Q_T. If abatement costs turn out to be relatively high, so that permit demand is given by curve D_2, the price of a permit would be driven up to P_T. Annual permits would be sold, and the total number of permits demanded would be Q_2.

This hybrid plan combines the key advantages of tax and permit policies. Like a tax, it places an upper limit on the marginal cost of abatement. Firms will never have to pay more than P_T, the price of an annual permit, to abate a unit of pollution, so no country would need to fear that the policy would strangle its economy in a vain attempt to meet unexpectedly expensive pollution targets. Because the total supply of permits would not be fixed, the policy would not guarantee precisely how much abatement would be done. However, it would ensure that the abatement done within a given country would be done at minimum cost. Moreover, marginal abatement costs would be equalized across all countries where the price of a permit rose to P_T.

The hybrid policy also avoids many of the distributional issues of an emissions tax. The block of perpetual permits could be distributed by the government to avoid the large transfers associated with a pure emissions tax. Moreover, any transfers that do occur (as a result of permit trades) take place within the private sector, rather than between the private sector and the government. The policy also

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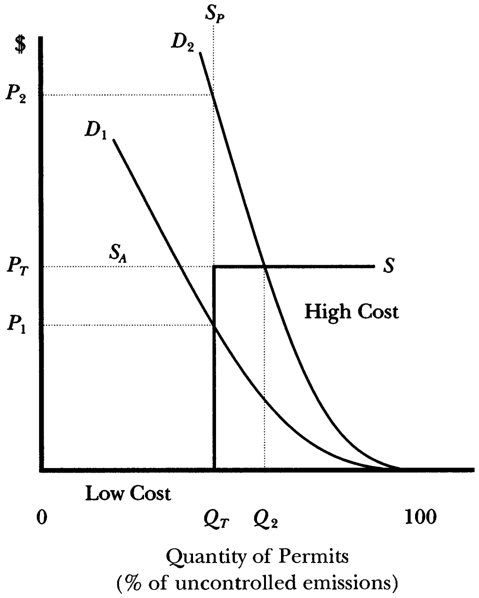
Figure 2
Market Equilibria in Low- and High-Cost Cases



minimizes transfers across national borders, because each national government can supply as many permits as desired at the capped price P_T, so purchasing permits from abroad becomes unnecessary.

The hybrid policy has built-in incentives for monitoring and enforcement. Since governments would receive revenue from selling annual permits, they would have an incentive to enforce the policy. In addition, firms will have an incentive to monitor one another, because any cheating by one firm would put its competitors at a disadvantage and would also diminish the value of permits held by other firms. With these built-in incentives for monitoring, little or no international monitoring would be needed.

Another benefit of the policy is that it would provide valuable information about the true marginal abatement cost curve. Many economists believe that reducing emissions of greenhouse gases would be quite costly, but others argue that emissions can be reduced substantially at low cost. A hybrid policy would help show which argument is correct.

The hybrid policy would be flexible and decentralized. The price charged for annual permits could be adjusted as needed when better information becomes available. It would be easy to add countries to the system over time: those interested in joining would only have to adopt the policy domestically—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 be willing to

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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. This advantage is very important: under a pure system of internationally tradable permits, the addition or withdrawal of any country would cause the world demand and supply of permits to shift, possibly leading to large swings in the price of the permits.

A final benefit is that the policy would be very transparent: to firms, it would look like a form of grandfathering.

Overall, a hybrid policy is an efficient and politically realistic approach to climate change.[7] It does not require a major sacrifice of sovereignty by participating countries, and it reduces greenhouse gas emissions without requiring countries to commit to rigid emissions targets that must be achieved at any cost. Together, these features remove the most formidable obstacles to the development of a sound international climate change policy.

Where Does Climate Change Policy Stand 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 subsequent decade, few substantive policies were implemented, and global emissions of greenhouse gases rose considerably. From that perspective, the UNFCCC has failed to achieve its goal. However, the convention did set up a mechanism under which negotiations could continue as periodic "Conference of the Parties" (COP) meetings. Between 1997 and 2001, there were seven COP meetings. They are commonly referred to by number, COP1, COP2 and so on, and they are summarized in Table 4.

The main decision reached at COP1 in 1995 was that the UNFCCC would have little effect on greenhouse gas emissions unless individual countries were held to "quantified limitation and reduction objectives within specified time-frames," an approach now described as setting "targets and timetables" for emissions reduction. All subsequent COP meetings have been devoted to designing an international treaty along those lines, in which participating countries would agree to achieve specific targets for emissions of greenhouse gases by a given date. The result is the Kyoto Protocol, which was initially adopted at COP3 in 1997 and has been revised and refined in subsequent meetings.

The key feature of the Kyoto Protocol is an appendix, known as "Annex B,"

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

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Table 4

Chronology of Major International Negotiations on Climate Change

1992: Earth Summit, Rio de Janeiro

Produced the United Nations Framework Convention on Climate Change (UNFCCC), a landmark agreement with the goal of "preventing dangerous anthropogenic interference with the Earth's climate system." Industrial countries listed in the treaty's "Annex I" were to adopt policies aimed at reducing their emissions to 1990 levels by the year 2000. However, no specific policies were required, and Annex I countries were only obligated to "aim" to reduce their emissions, not actually to reduce them. The UNFCCC was signed by 153 countries and entered into force on March 24, 1994. It was ratified by the United States in October 1992.

1995: COP1, Berlin

Adopted the "Berlin Mandate," a declaration that the UNFCCC would have little effect on greenhouse gas emissions unless Annex I countries were held to "quantified limitation and reduction objectives within specified time-frames," an approach now described as setting "targets and timetables" for emissions reduction. Established a two-year "analytical and assessment phase" to negotiate a comprehensive set of "policies and measures" that should be taken by Annex I countries. No new commitments or obligations were imposed on countries outside Annex I.

1996: COP2, Geneva

Called for the establishment of legally binding emissions targets as proposed at COP1. Rejected the COP1 proposal that uniform policies be imposed in favor of allowing Annex I countries the flexibility to develop their own policies.

1997: COP3, Kyoto

Adopted the "Kyoto Protocol," in which most Annex I countries were assigned legally binding emissions targets to be achieved by 2008–2012. The average target was about 95 percent of the country's emissions in 1990. Many details of implementation were left for future negotiations.

1998: COP4, Buenos Aires

Adopted a two-year plan of action to design mechanisms for implementing the Kyoto Protocol. Issues discussed included financial transfers and Clean Development Mechanism (CDM) for developing country participation. Also discussed issues for incorporating "carbon sinks."

1999: COP5, Bonn

Primarily devoted to monitoring progress on the work program adopted at COP4.

2000: COP6, The Hague

Intended to finalize details on implementation of the Kyoto Protocol. Negotiations ended without agreement. Many issues were unresolved: how the mechanisms in the Protocol would operate; what measures would be used to enforce compliance; how large allowances would be for "sinks" that remove carbon dioxide from the atmosphere; and whether there would be restrictions on the use of the Protocol's flexibility mechanisms.

2001: COP6bis, Bonn (July)

Continuation of COP6 following the stalemate at The Hague. However, President Bush declared in March 2001 that the United States would not participate in the Kyoto Protocol. Other Annex I countries agreed to proceed without the United States. Large sink allowances were granted to Japan and Canada. Produced a set of recommendations on implementing the Protocol that were to be discussed at COP7.

2001: COP7, Marrakesh (October)

Formally adopted most of the recommendations of COP6. Finalized rules for use of flexibility mechanisms, especially the Clean Development Mechanism. Also, established a "Compliance Committee" to "facilitate, promote and enforce" compliance with the Protocol. In the event of noncompliance, the "Enforcement Branch" of the Compliance Committee may deduct 1.3 times the amount of the violation from the violator's emissions allowance for the next commitment period. The violator may also be barred from using the flexibility mechanisms. Also finalized the accounting procedures to be used for sinks.

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that specifies annual greenhouse gas emissions limits for 38 industrialized countries—essentially the developed members of the OECD plus about a dozen countries that were formerly part of the Soviet Union.[8] Each country's limit is expressed as a percentage of its emissions in 1990 (a few countries are allowed to use a different year). The limits range from 92 to 110 percent: 92 percent for most European countries, 93 percent for the United States, 94 percent for Canada and Japan, 100 percent for Russia, 110 percent for Iceland and various other values for other countries. If all Annex B countries complied with the Protocol, emissions for the group as a whole would end up 5 percent below the corresponding value from 1990.

The Protocol considers a country's greenhouse gas emissions to be the number of metric tons of carbon dioxide that would produce the same total amount of warming as the country's actual emissions of six gases—carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride—plus the carbon dioxide equivalent to the net effect of any changes in the country's land use and forestry on greenhouse gas concentrations. The latter is included to allow countries to offset part of their fossil fuel emissions by planting trees or undertaking other activities—collectively known as "sinks"—that remove carbon dioxide from the atmosphere. Each country's base year emissions are multiplied by its Annex B percentage limit to give its initial allotment of "Assigned Amount Units," which are essentially tradable permits for greenhouse gas emissions.

The Protocol provides three "flexibility mechanisms" that an Annex B country can use: emissions trading, "Joint Implementation" and the "Clean Development Mechanism." Emissions trading is straightforward: one Annex B country may buy unused permits from another. Joint Implementation is a bit more complicated, but essentially allows one Annex B country to undertake an emissions reduction project in another Annex B country in exchange for some of the second country's emissions permits. Both mechanisms involve only Annex B countries and reallocate permits without affecting total Annex B emissions. The Clean Development Mechanism, in contrast, is designed to extend participation in the Protocol to non-Annex B countries. Under this mechanism, an Annex B country can receive emissions credits for undertaking a suitable emissions-reducing project in a non-Annex B host country. The project must be certified by an independent agency to reduce the host country's emissions beyond what would have occurred otherwise. It is by far the most complicated of the Protocol's flexibility mechanisms: the Clean Development Mechanism rules approved at COP7 run to 28 pages, compared with 5 pages for emissions trading. The complexity is largely due to the inherent difficulty of establishing what emissions would have been in the absence of a given emissions reduction project.

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[8] The countries listed in Annex B are a subset of a group of industrial countries identified in Annex I of the original UNFCCC. Annex B excludes Belarus, which had not ratified the UNFCCC by the time COP3 was held, and Turkey, which requested that it be removed from Annex I. Strictly speaking, the Kyoto Protocol limits the emissions of UNFCCC Annex I countries to the values given in the Protocol's Annex B. However, we will refer to the group of countries having limits as simply "Annex B countries."

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Countries having too few permits or credits in 2012 to cover their emissions during 2008–2012 would be out of compliance with the Protocol. In the event of noncompliance, the "Enforcement Branch" of the Compliance Committee may deduct 1.3 times the amount of the violation from the violator's emissions allowance for the next commitment period (possibly 2013–2017). The violator may also be barred from using the flexibility mechanisms.

Although the Kyoto Protocol was signed in 1997, it has yet to enter into force. The Protocol specifies that two conditions must be met before it becomes binding: it must be ratified by at least 55 countries, and it must be ratified by countries accounting for at least 55 percent of Annex B emissions. By the end of 2001, however, the Protocol had been ratified by only 40 countries and not by a single member of Annex B. Moreover, the United States withdrew from negotiations in March 2001, making the second condition especially difficult to satisfy. The United States alone accounts for about 33 percent of 1990 Annex B emissions; without it, the withdrawal of countries accounting for an additional 13 percent of emissions would render the 55 percent condition impossible to meet.

Even if it did enter into force, the post-COP7 Kyoto Protocol would have much less effect on worldwide greenhouse gas emissions than originally intended. In addition to the departure of the United States, the Protocol's targets were weakened during COP6 and COP7, which granted large allowances for "sinks" to Canada, Japan and Russia. Years of negotiation, in other words, have produced only a weak protocol that is unlikely to enter into force. The reason is that the fundamental approach underlying the Kyoto Protocol, setting targets and timetables for emissions reductions, is seriously flawed. We will briefly outline four key problems.

First, the Kyoto Protocol would force emissions below 1990 levels and hold them there without regard to the costs and benefits of doing so. Studies to date provide little justification for that particular target. The Protocol would only reduce the rate of warming slightly, not prevent it entirely. As a result, the Protocol's benefits are only a fraction of the estimated damages from uncontrolled warming. In addition, the Protocol's effect on temperatures is decades away, while its costs would begin immediately. Thus, for most developed countries, including the United States, the Protocol provides only small environmental benefits, but imposes significant costs. For example, Nordhaus and Boyer (1999) find that the Protocol does not "bear any relation to an economically oriented strategy that would balance the costs and benefits of greenhouse gas reductions." They calculate that the worldwide present value cost of the Kyoto Protocol would be $800 billion to $1,500 billion if it were implemented as efficiently as possible, while they estimate the present value of benefits to be $120 billion. Other studies reach similar conclusions. Tol (1999), for example, finds that the Kyoto Protocol would have a net present value cost in excess of $2.5 trillion and comments that "the emissions targets agreed in the Kyoto Protocol are irreconcilable with economic rationality."

Second, the principal international policy instrument of the Kyoto Protocol would be a system of internationally tradable emissions permits (although countries

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could take other domestic actions to reduce greenhouse gases as well). International permit trading runs the risk of being highly inefficient, given uncertainties in the marginal cost of abating greenhouse gas emissions. But international permit trading has a more serious political flaw: it would probably generate large transfers of wealth between countries. After all, trading and transfers are inextricably linked: if trading is likely to be important for efficiency, it is also likely to produce large transfers. Consider a 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 to $200 a ton is well within the range of estimates. At such a price, U.S. firms would need to spend $27 billion to $54 billion to buy pollution permits from abroad every year. That amount exceeds the $26 billion that manufacturing firms spent to operate all pollution abatement equipment in 1994 (the most recent year for which data is available from the U.S. Bureau of the Census, 1996), and it dwarfs the $8 billion spent by the U.S. government in 2000 for international development and humanitarian and foreign aid (U.S. Office of Management and Budget, 2001). Transfers of wealth of this magnitude nearly guarantee the treaty would never be implemented.

A third problem with the Kyoto Protocol is that it would put enormous stress on the world trade system. The balance of trade for a developed country that imported permits would deteriorate substantially, possibly leading to increased volatility in exchange rates. Developing countries that exported permits under the Clean Development Mechanism would see their exchange rates appreciate, causing their other export industries to decline or to collapse. Moreover, revenue from the Clean Development Mechanism would come with strings attached: much of it would have to be invested in improved energy technology to reduce emissions. Since this strategy is unlikely to be ideal for long-term economic development, it would make the policy unattractive to developing countries. In fact, one of the main reasons that the Kyoto Protocol only set up a system of trading among the Annex B countries (the developed economies and the former Soviet Union) is because developing countries have been so unenthusiastic about international permit trading. However, permit trading among Annex B countries would do little to lower abatement costs, since the countries have fairly similar technology.

A fourth problem with the Kyoto Protocol is that no individual government has an incentive to police the agreement. After all, monitoring polluters is expensive, and punishing violators imposes costs on domestic residents in exchange for global climate benefits that, by their nature, will accrue largely to foreigners. Governments will have a strong temptation to look the other way when firms exceed their emissions permits. For the treaty to be viable, however, each participating country would need to be confident that the other participants were enforcing it. The Kyoto

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approach can only work if it includes an elaborate and expensive international mechanism for monitoring and enforcement.

Ironically, even if the Kyoto Protocol were ratified immediately, it does not actually constrain emissions for years. Emissions from the United Kingdom, Germany and especially Russia are below 1990 levels already, as was shown in Table 1. The reasons are varied, but have nothing to do with climate change policy: emissions in the United Kingdom dropped as a result of changes in its coal industry begun under the Thatcher government; German emissions fell because reunification led quickly to the elimination of many energy-inefficient activities in what was once East Germany; and Russian emissions were reduced because the Russian economy collapsed in the 1990s. As a result, total emissions from Annex B countries are currently below 1990 levels. If the Protocol goes forward without the United States, emissions from the remaining countries would be about 400 million metric tons below the target. It is unlikely that emissions would be significantly constrained during the Protocol's first commitment period, 2008 to 2012. Moreover, the Protocol's emissions targets apply *only* to the 2008–2012 period: limits for future periods remain to be negotiated. If the Protocol fails to constrain emissions in the first commitment period, it will have done nothing to reduce the risks posed by climate change.

All in all, the Kyoto Protocol is an impractical policy focused on achieving an unrealistic and inappropriate goal. The Bonn and Marrakesh revisions in 2001 postponed the Protocol's collapse by reducing its stringency, but did nothing to address the underlying design flaws. Further negotiations will accomplish little of substance as long as they remain focused on establishing a targets-and-timetables approach to climate change policy.

Conclusion

Because so little real action has been taken on climate change to date, an opportunity remains for an efficient and practical policy to be adopted. A hybrid climate change policy has much to offer. It is flexible enough to deal with the enormous uncertainties regarding climate change. It provides individual governments with an instrument to limit and to channel the distributional effects of the policy, reducing the obstacles to ratification. Moreover, it creates incentives for governments to monitor and to enforce the policy within their own borders. It is a practical policy that would reduce greenhouse gases in a cost-effective manner.

International negotiations to date have produced a very different policy, the Kyoto Protocol, which is deeply flawed. The Protocol fails to acknowledge the uncertainties surrounding climate change and requires countries to commit themselves to achieving rigid targets and timetables for emissions reductions, even though the cost of doing so could be very high, and the benefits are uncertain. The Protocol never had any real chance of ratification by the U.S. Senate and, in

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mid-2001, was rejected by the Bush administration. Negotiations over the Protocol's details continue to be held, but the Protocol appears increasingly unlikely to have any effect or even to enter into force.

With leadership by the United States, however, climate policy could be shifted in a more practical and efficient direction. A good first step would be for the United States, perhaps joined by other large emitters, to adopt a modified form of the hybrid policy unilaterally. The government could immediately distribute perpetual emissions permits equal to the U.S. commitment under the Kyoto Protocol, but with one important caveat: firms would not be *required* to hold emissions permits unless an international agreement were reached on climate change. Essentially, the government would distribute contingent property rights for greenhouse gas emissions. Such a step would be in the self-interest of the United States, because it would allow financial markets to help manage the risks of climate policy. For example, a firm worried that it would be unable to comply with a future climate regulation could reduce its risk by buying extra permits, or even options on extra permits, as a hedge. A firm able to reduce its emissions at low cost could sell permits (or options) now. Of course, pricing these permits would present a short-run challenge for financial markets, since the price would need to reflect if or when carbon emissions will be regulated. But financial markets confront this kind of problem every day. Within a very short time, an active market would develop with prices that reflected both the likelihood of a policy taking effect and its probable stringency. Indeed, active markets have already been formed for trading privately created emissions permits. Such a step might jump-start and redirect the course of international climate change negotiations.

Climate change is a serious environmental risk that will likely grow in importance over the coming decades. There is still an opportunity for climate change policy to take an efficient and practical form, but leadership will be needed to keep the opportunity from being lost.

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