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Climate Change:
An Agenda for Global Collective Action

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Prepared for the conference on "The Timing of Climate Change Policies"
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Introduction

Over the past decade, and especially over the past few years, climate change has emerged as one of the most important issues facing the international community. The reasons are almost obvious: We share a common planet; we lack a viable alternative living space should we destroy the atmosphere of this common planet; concentrations of so-called greenhouse gases have increased markedly during the past century; and the scientific evidence suggests that continued increases in greenhouse gas concentrations are likely to have significant effects on the climate and thereby other aspects of the earth's ecology.

A global consensus now exists that climate change represents a significant potential threat to the world's well-being. But there is disagreement about how and when to address that threat. The industrialized economies, with the exception of the United States, agree upon a particular approach to reducing greenhouse gas emissions. Yet the exceptions are crucial: An effective framework for reducing greenhouse gases will eventually require the participation of the United States and the developing countries. And despite the opposition of the United States to even the current target reduction levels, some observers argue that the targets should be more aggressive.

This conference focuses on the question of how rapidly emissions *should* be reduced. But if that question is to be of more than academic interest, it must be set in the current political context, in which the largest emitter of greenhouse gases refuses to adopt the current emission target levels, and the developing world, which will be contributing more than 50 percent of the world's emissions by 2020, has not even agreed to *voluntary* emission reduction commitments.

To motivate the discussion of both the timing and magnitude of emissions mitigation policy, the paper begins with an overview of the underlying science and

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economics. Understanding the uncertainties and differences in the timing of costs and benefits of climate change mitigation helps frame the extensive discussion of political economy issues that we examine in the second section. Specifically, we explore the interaction of economic and political concerns in enforcing emissions commitments and encouraging developing country participation within the "voluntaristic" framework entailed by the current system of global governance. Given these political economy constraints, in the third section we evaluate the Kyoto Protocol and alternative formulations to climate change policy.

We conclude that modifications to the Kyoto framework are required to advance the effort to address climate change. At the very least, a thorough re-examination of alternative frameworks may prove helpful in building a global consensus behind a more effective strategy. The final section concludes with a discussion of one promising approach to addressing climate change: a flexible hybrid system that combines a permit trading program with the ability of governments to sell additional permits at a given maximum price.

It is important to note that our preferred approach does *not* necessarily involve less aggressive global emission reductions in the short run than called for under the Kyoto Protocol. Rather, the approach is intended to provide a mechanism for ensuring that short-run emission reductions are politically viable, by including economic and political protections against unexpectedly high costs. Indeed, by improving the political viability of emission reductions, the hybrid system could play a crucial role in beginning the process of addressing climate change in the long run.

I. The Timing of Benefits and Costs Associated with Climate Change Policy

While environmental policies usually entail up-front costs (such as investment in a scrubber) to deliver benefits spread out over the future (such as reduced ambient particulate matter), few environmental risks exhibit such a stark divergence in the timing of costs and benefits as climate change.[2] The distant time-frame of climate change effects, as well as the lack of experience in regulating greenhouse gas emissions, result in substantial uncertainties in the understanding of both the benefits and costs of climate change mitigation. This section provides an overview of the current state of knowledge about the science of climate change, the potential risks posed by a changing climate, and the costs of abating greenhouse gas emissions to mitigate these climate risks.

The Science of Climate Change

The earth's climate reflects, in part, the presence of so-called greenhouse gases in the atmosphere. These gases (including carbon dioxide, methane, nitrous oxide, and others) serve to trap energy reflected by the Earth's surface and cause the planet to be much warmer than it would otherwise be. The magnitude of the greenhouse effect is driven by the atmospheric concentrations of these greenhouse gases. For example, analysis of ice core data shows a strong historical correlation between the concentration

[2] Policies under the Montreal Protocol to address stratospheric ozone depletion are an important exception.

of carbon dioxide and surface temperature. Similarly, in the future, the ongoing increase in greenhouse gas concentrations is expected to increase the global average temperature and cause other changes to the global climate.

Since 1750, the atmospheric carbon dioxide concentration has increased by more than 30 percent (from 280 parts per million, or ppm, to 365 ppm), while methane has increased by more than 150 percent and nitrous oxide has increased by more than 15 percent. Carbon dioxide and methane concentrations are higher now than at any time in the past 420,000 years.[3] The global average temperature increased between 0.4°C and 0.8°C over the past century, with most of the warming occurring prior to 1940 and over the past 25 years.[4] Likewise, global average sea level rose about 0.1 to 0.2 meters over the past 100 years.[5]

The Intergovernmental Panel on Climate Change (IPCC) notes that fossil fuel-based carbon dioxide emissions are "virtually certain to be the dominant influence on the trends in atmospheric CO_2 concentration during the 21st century."[6] This dominance reflects the half-life of carbon dioxide: emissions can remain in the atmosphere for 100 years or more, so there are long lags between changes in the *level* of emissions and changes in the *stock* of atmospheric greenhouse gases.

The two most recent expert assessments of the science of climate change – the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report and the National Research Council response to the White House – confirm that human activity has influenced the global climate over the past century and is projected to have potentially significant impacts on the global climate over this century. For example, the opening of the recent National Research Council report noted:

> "Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes are also a reflection of natural variability. Human-induced warming and associated sea level rises are expected to continue through the 21st century."[7]

To understand better the potential human influence on the global climate in the future, the IPCC developed a set of long-term scenarios of greenhouse gas emissions.[8] The scenarios do not reflect proposed greenhouse gas mitigation policies, such as the Kyoto Protocol; they are in this sense "no-new-policy" or "business-as-usual" scenarios.

[3] Albritton et al 2001, p. 7.
[4] Albritton et al 2001, p. 2; NRC 2001, p. 16.
[5] Albritton et al 2001, p. 4.
[6] Albritton et al 2001, p. 12.
[7] NRC 2001, p.1.
[8] Nakicenovic et al 2000.

The IPCC used six illustrative emissions scenarios in various climate models to project future atmospheric concentrations of greenhouse gases. For these illustrative scenarios, the IPCC projected that carbon dioxide concentrations in 2100 would range between 540 and 970 ppm (about 50 to 165 percent greater than the current concentration).

Higher greenhouse gas concentrations would increase global average temperatures over the 1990 to 2100 period by 1.4°C to 5.8°C, according to climate models. The rate of warming over the next century would very likely be greater than any temperature change experienced over the past 10,000 years. This warming would increase the frequency of intense precipitation events, and increase summer mid-latitude continental drying and the associated drought risk. It would also cause the global average sea level to rise by 0.09 to 0.88 meters over this century.[9]

Uncertainties in Climate Science

While the IPCC noted that "confidence in climate models to predict future climate has increased,"[10] significant uncertainties still exist regarding the type, magnitude, and distribution of effects of a changing climate. For example, some climate models operated by the IPCC show a weakening by 2100 of thermohaline circulation (e.g., the gulf stream carrying heat to Europe), but none show it being eliminated completely (which would leave Europe with potentially significant *decreases* in average temperature while the rest of the planet would continue to warm). In addition, some have speculated about the potential for the West Antarctic ice sheet to break up, causing rapid and substantial rises in the sea level. Such an outcome is considered to be very unlikely during the next century, but the IPCC notes that "its dynamics are still inadequately understood, especially for projections on longer time-scales."[11]

The magnitude of warming projected for 2100 noted above ranges from lower to upper bound by a factor of four. The uncertainty both within and about this range reflects uncertainties regarding a variety of parameters, including forecast greenhouse gas emissions; impacts of clouds and aerosols on warming; feedback effects from, and carbon storage by, oceans and some terrestrial ecosystems; and natural climate variability. Further complicating the understanding of climate change is the challenge in identifying the distribution of effects at fine scales. Although global climate models have roughly converged over the past decade in their estimates of globally average impacts (e.g., mean increase in surface temperature), they still often yield divergent assessments of regional and local effects.

The Economics of Climate Change

Warmer temperatures, a changing and more intense hydrologic cycle, and rising sea levels can have a variety of economic effects. Climate change can directly influence the production of some goods and services, such as agricultural crops and forest timber

[9] Albritton et al 2001, pp. 13, 15-16.
[10] Albritton et al 2001, p. 9.
[11] Albritton et al 2001, p. 16.

products. Rising sea levels and more intense weather events, such as floods and hurricanes, can also cause extensive damage to property. Furthermore, climate change can adversely affect individuals' well-being and make individuals worse off by degrading valued ecosystems and biodiversity.

Policies to mitigate greenhouse gas emissions and thus limit the build-up of atmospheric concentrations of greenhouse gases would provide benefits by mitigating these adverse economic impacts. In addition, actions can be taken to adapt to the changing climate and thus lower the costs of climate change, although it is important to note that adaptation itself also entails costs.

The Costs of Climate Change

Several studies have estimated the costs of unabated climate change, in order to understand the benefits of mitigating climate change risks.[12] Many of these studies focus on increasing atmospheric carbon dioxide concentrations to twice the pre-industrial level (about 560 ppm) in 2100, which is an ambitious target to achieve given the business-as-usual paths for emissions. The studies find that developed countries would bear costs on the order of one to two percent of gross economic output from such changes, while developing countries could bear higher costs as a share of their economic activity. Accounting for market and non-market economic effects, the IPCC provided a "best-guess central" estimate that global damages would amount to 1.5 to 2 percent of global economic output under such a climate change scenario.[13] To place these estimated economic losses into context, annual economic damages on the order of two percent of 2000 U.S. economic output would come to about $200 billion.

Several aspects of a changing climate are worth particular attention:

- Agriculture. A substantial amount of research has focused on the potential effects of climate change on agriculture. For the United States, the balance of the research shows that for modest amounts of climate change, the net impact on agricultural output will be rather small; some studies show small net benefits, while others show small net costs.[14]

- Forestry. A changing climate is also likely to affect the forestry sector. Higher carbon dioxide concentrations could benefit forest growth, but changes in the hydrologic regime and potential changes in the pestilence regime may negatively affect timber output. Cline (1992) estimated that the decline in commercial forests under a doubling of pre-industrial carbon dioxide concentrations by 2100 would be on the order of 40 percent. More recent research indicates that, especially with effective resource management, estimated forest decline may be much less than earlier research had suggested.[15]

[12] See Cline 1992, Nordhaus 1994, Pearce et al 1996, and Schneider and Thompson 2000.
[13] Pearce et al 1996.
[14] Adams et al 1999.
[15] Sedjo and Sohngen 2001, p. 78.

- Biodiversity. Research has focused on the threat that a changing climate may pose to many species, especially those with a limited habitat. The expected poleward migration of forests may effectively strand some species due to natural and human barriers to species migration. Moreover, changes in hydrologic and temperature regimes could influence other ecosystems, such as coral reefs.

- Coastal Areas. The rising sea level associated with climate change will impose costs in terms of coastal property damage (e.g., from higher storm surges, lost land area, and saltwater intrusion in some drinking water aquifers).[16] Protecting developed coastal areas in the United States could involve capital costs exceeding $100 billion.[17] Nordhaus (1994) estimated larger damages as a share of economic output for coastal activities than for any other sector of the economy.[18]

- Extreme Weather Events. A changing climate will likely cause both an increase in the frequency of precipitation events and in the intensity of these events. Weather extremes, from flooding to drought, may become more common with climate change. Further, intense storms, such as hurricanes and cyclones, may become more intense and more common. Cline (1992) estimated damages of less than $1 billion per year based on a 50 percent increase in the damage associated with hurricanes affecting the United States. However, hurricane and cyclone activity may carry greater costs to island countries and some sub-tropical countries, in terms of property and resource damage as well as human life.[19]

- Heating and Cooling. A warmer climate would make winters milder, providing some amenity benefits by offsetting cold, severe weather, but it would also make summers hotter and potentially increase the frequency and magnitude of heat waves.[20] Depending on the extent of the warming, the reduction in heating expenditures appear to exceed the potential increase in expenditures for air conditioning in the United States, resulting in positive net benefits on the order of several billion dollars per year.[21] However, for many developing countries situated in warmer climates than the United States, increased cooling costs would dominate any potential change in their virtually non-existent heating bills, resulting in net costs for them. In addition, recent research appears to show that changes in heat wave mortality may be more significant than changes in severe cold weather mortality.[22]

[16] Frederick 2001. It is important to note that due to the long time lag between warming and thermal expansion of the ocean and additional melting at polar regions and glaciers, even halting the increase in atmospheric concentrations at the end of this century would not stop the sea level from rising for several hundred more years.
[17] Pearce et al 1996, p. 191.
[18] Nordhaus 1994, p. 51.
[19] Pearce et al 1996.
[20] Pearce et al 1996, p. 193, Cline 1992, p. 11.
[21] Pearce et al 1996, p 19.
[22] Balbus and Wilson 2000, p. 1.

- Local Air Quality. A warmer climate could also exacerbate urban air pollution. Ground-level ozone (smog) increases in the presence of high temperatures. More high temperature days, especially during the summer months, would increase the number of days when ozone concentrations exceed the standard set to protect public health. Estimates by Cline (1992) and Fankhauser (1995) find that climate-related ozone damages could carry costs on the order of several billion dollars annually in the United States.

Other potential effects may be even more difficult to quantify. For example, tropical climates are associated with a higher incidence of disease. Depending on how rapidly changes in climate occur, and how quickly disease patterns respond to these changes, full immunological defenses may not emerge in time to prevent a marked increase in disease. Such effects represent but one example of transition costs; even if adaptations are possible in the longer run, the change in climate can impose large costs in the meanwhile.

The magnitude of many of these climate change damage categories depends in large part on the ability of humans and natural ecosystems to adapt to the changing climate. Although warming is already occurring, many of the most significant risks to the environment from climate change will not occur for many years. This lag provides time for individuals and nations to consider actions to adapt to the changing climate.[23] The ability to adapt, however, varies across countries, in large part due to differences in income. Wealthy countries have more resources and more site-specific technology to adjust to a changing climate than poorer countries. Even transfers of income to assist developing countries in adaptation may not be completely successful without appropriate technological development for their circumstances.

The damages from a changing climate are very uncertain, partially reflecting the uncertainties in climate change science. For example, the 1.5 to 2 percent of economic output estimate mentioned above does not account for possible "surprise" threshold events, such as the interruption of the thermohaline cycle, which could impose substantial socioeconomic and environmental damages. But despite the uncertainty, it is very likely that ongoing climate change will impose economic and social costs on the world. It is therefore important to compare those costs with the costs of reducing emissions (and ultimately stabilizing concentrations).

[23] Consider the case of a farmer adjusting to climate change. With more refined and locally-specific climate forecast information, a farmer could determine if it would be economic to invest in a new irrigation system to offset a change in the hydrologic regime expected under climate change. If the economic benefits of reduced output under climate change are lower than the net economic benefits of investing in irrigation (the value of higher output less the costs of the new irrigation system), then the farmer should proceed with the investment. Alternatively, the farmer could consider less-capital-intensive options, such as drought-resistant seeds. However, the ability of the farmer to adapt is weakened by faster rates of change as well as by greater levels of climate change. Note that adaptation may be reflected in migration by both humans and natural ecosystems. Regions that are more vulnerable to climate change, especially in terms of threats to agricultural production and water supply, may experience significant out-migration as people seek a better living environment.

The Costs of Abating Greenhouse Gas Emissions

Abating greenhouse gas emissions would impose costs on the economy by requiring firms and individuals to modify their behavior in order to reduce emissions. To estimate the costs of abating greenhouse gas emissions under a specific policy scenario, the level of emissions over time in the policy scenario is compared with the level of emissions over time in the business-as-usual scenario. Understanding the base case emissions is crucial for assessing the stringency of any policy scenario: the same policy scenario may appear very modest compared to a low emissions growth business-as-usual case, but very ambitious relative to a high emissions growth business-as-usual case. Moreover, the economic and energy structure factors that influence the business-as-usual case will likely influence the responsiveness of the economy to any policies aimed at abating emissions. The business-as-usual case for the cost analysis should be identical to the scenario used to estimate the damages from climate change.

The "short-term" Energy Information Administration (EIA) emissions forecasts provide estimates of carbon dioxide emissions over the next 20 years. Emissions forecasts reflect projected energy prices and economic growth, and their subsequent effects on the development of the energy sector and energy consumption, as well as an assumed rate of technological advancement. For the United States, the EIA (2000) base case forecast estimates that carbon dioxide emissions will reach 2,041 million metric tons of carbon equivalent (MMTCE) by 2020, roughly 35 percent above the 1999 emissions level (see Table 1). The results are particularly sensitive to economic growth rates and technological change, however, as the table demonstrates.

Emission reductions are measured relative to such a baseline. For example, a variety of economic models have been used to estimate the costs of reducing emissions from the business-as-usual path to the one specified under the Kyoto Protocol. The United States commitment under the Kyoto Protocol, which it has not ratified, involved a mandatory emissions target of seven percent below 1990 levels by 2008-2012.[24]

The Stanford University Energy Modeling Forum (EMF) coordinated an assessment of the costs of complying with the Kyoto Protocol by 13 modeling teams from the United States, Japan, Australia, and Europe.[25] These modeling teams had developed global energy-economic models that could provide estimates of the costs of a carbon dioxide tax or a carbon dioxide tradable permit system.

For the United States, the estimated marginal cost of complying with the Kyoto Protocol solely through domestic emissions abatement ranges from about $100 per ton to $500 per ton (see Figure 1). The average marginal cost across the models is slightly less than $250 per ton. The models found that the costs of domestic-only achievement of the Kyoto emissions targets would be even higher for Japan. Some models estimated that the

[24] The seven percent figure is somewhat misleading, since the baseline for three of the gases (PFCs, HFCs, and SF6) is 1995, not 1990. Furthermore, the treatment of carbon sinks in the Kyoto Protocol could affect the target level relative to 1990 emissions.
[25] Weyant and Hill 1999, Kyoto Special Issue of the Energy Journal 1999.

European Union would experience lower marginal costs than the United States, while others showed higher marginal costs.

Given the differences in marginal costs among the developed countries, the costs of complying with the Kyoto targets would fall significantly under an efficient international trading system. Full Annex I trading would lower the marginal costs for the United States, the EU, and Japan.[26] The EMF models estimated that the Annex I tradable permit price would range between about $20 and $270 per ton, with an average of less than $100 per ton.

Expanding trading to include developing countries would further reduce the costs of compliance. Under such a trading scheme, developing countries could garner benefits by reducing emissions below their targets and selling unused emissions permits to developed countries, while the developed countries benefit from the reduced costs of meeting the emission target. In the EMF global trading scenarios, the modeling teams assumed that developing countries adopted emissions targets set equal to their 2010 business-as-usual emissions level. The results suggested permit prices averaging $50 per ton, with seven models estimating the permit price under global trading to be about $30 per ton or less.

Subsequent research has illustrated that accounting for other greenhouse gases and carbon sequestration can further lower the costs. For example, researchers at M.I.T. found that including non-carbon dioxide greenhouse gases in a tradable permit system could reduce the costs of complying with Kyoto by up to 25 percent.[27] Research led by a group at the University of Illinois found that including methane along with carbon dioxide could reduce abatement costs by a similar magnitude.[28]

Uncertainty in the Costs of Emissions Abatement

Substantial uncertainties exist regarding the cost of abating greenhouse gas emissions. Indeed, these uncertainties are reflected in part by the range in U.S. permit prices -- $100 to $500 per ton -- in the EMF exercise for the autarky reduction scenario. This range may not instill much confidence in policymakers, who must decide whether to proceed with policies to abate greenhouse gas emissions despite wildly varying cost estimates of doing so. We highlight several key contributors to such uncertainty, both in the "near term" (the next 10 to 20 years) and longer term (the next century and more).

- BAU Emissions Forecasts. We noted above the range in the EIA business-as-usual emissions forecasts for the United States through 2020. The uncertainties become even more substantial as the horizon shifts further into the future. For example, the IPCC's recent effort to develop long-term emissions scenarios yielded six illustrative emissions scenarios with global carbon dioxide emissions

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[26] The Annex I countries are the industrialized nations with binding emissions commitments.
[27] Reilly et al 1999.
[28] Hayhoe et al 1999.

levels that vary by a factor of *six* in 2100.[29] This large range reflects a variety of assumptions about long-term economic growth and global economic integration, population growth, technological innovation, preferences for environmental quality and "sustainable development," political development, and other factors.

- Substitution. The costs of a policy designed to reduce carbon dioxide emissions will depend in large part on how easily consumers and producers can substitute away from carbon-intensive activities towards carbon-lean ones.[30] The ability to substitute is clearly a function of time. More lead time allows firms to incorporate the effects of future regulatory policies into their planning and investment decisions. Since some energy-related investments can have long lifetimes (for example, a power plant can easily last a half century and an automobile can last 10 to 15 years or more), substitution elasticities are higher in the long term (when equipment must be replaced in any case) than in the near term. The magnitude of the substitution elasticities can be important. For example, some models are more optimistic than others in terms of the substitution of natural gas plants for coal-fired plants, resulting in lower costs than the less optimistic models.[31]

- Endogenous Technological Change. Most models of emissions abatement assume that technological change is exogenous. In such models, assigning a price to carbon emissions (either through tradable permits or taxes) effectively stimulates the deployment of carbon-lean and carbon-free technologies, but it does not induce additional technological change. These models typically assume that energy efficiency in the U.S. economy improves by about one percent per year, regardless of the emission reduction strategy. The rate of technological change, however, could substantially alter the costs of addressing climate change over the next century. Accounting for the effects of policy on innovation could provide more realistic estimates of the long-run costs of emissions abatement, although recent work indicates that induced technological change could have only modest effects on the timing and magnitude of emissions abatement.[32]

- Policy Instrument Effectiveness. The models used to evaluate carbon dioxide abatement policies implicitly assume a perfectly efficient domestic and international emissions trading system (or emissions tax). Although the United States has some experience with tradable permits, few other countries do. Moreover, the U.S. experience pales in comparison to the magnitude of a greenhouse gas mitigation policy. Virtually every kind of economic activity could be affected by such a policy. The substantial heterogeneity in emission sources presents significant challenges for policy design, as does the international nature of the climate change problem. Thus, although a domestic program could

[29] Nakicenovic et al 2000.
[30] Jorgenson et al 2000.
[31] Bernstein and Montgomery 1998.
[32] Goulder and Mathai 2000.

potentially be developed and deliver substantial economic gains,[33] the probability of a relatively effective international emissions trading regime operating in the next 5 to 10 years is much lower. The world has been working on international trade rules for 50 years, with more work still to be completed. It seems unlikely that the world could create a "commodity" worth hundreds of billions of dollars per year and develop perfectly efficient institutions for the exchange of this commodity in a few years.

- Diffusion of Efficient Technologies. Marked differences exist in energy and emission efficiency both across and within countries. Economic theory does not provide good explanations for this phenomenon, other than the tautological observation that it appears to be caused by problems of information and other impediments to the dissemination of innovation. Uncertainty exists about the extent to which changes in policy or public attention could accelerate the diffusion of best practices.[34] The conceivable magnitude of emission reductions if best practices were quickly adopted is large.

II. The Political Economy of Long-Term Greenhouse Gas Mitigation

The ultimate objective of international climate policy under the Framework Convention on Climate Change (FCCC) is to stabilize atmospheric greenhouse gas concentrations at a safe level.[35] *If* there were an agreement about an acceptable ultimate concentration,[36] the question of how that concentration level were achieved would be a simple problem in the calculus of variations. The present discounted value of costs would differ across alternative paths, and one would simply choose that path which minimized the present discounted value of costs.[37]

[33] While we share the view of many economists that an "upstream" tradable permit system with permits based on the carbon content of fuels could be feasible and much more efficient than downstream alternatives, much of the political attention on downstream approaches (whether through utility sector tradable permit programs or CAFE) casts doubt on the potential for implementing the preferred upstream approach. Moreover, extending a tradable permit program to other greenhouse gases would be challenging regardless of the carbon program due to monitoring issues, appropriate trade conversion values, etc.

[34] This issue is related to, but somewhat distinct from, the substitution issue mentioned above. The focus here is primarily whether non-price mechanisms (such as the bully pulpit) could induce more firms and individuals to adopt best practices. The substitution elasticity issue, on the other hand, primarily involves the responsiveness of firms and individuals to a change in the relative price of emissions at different time horizons.

[35] UNFCCC Article 2.

[36] This is obviously a big "if." We believe that although policymakers may agree now that the world should aim for 2100 greenhouse gas concentrations below business as usual (even if they could not agree on the precise BAU level), it would be impossible to secure any agreement on the appropriate reduction of concentrations below BAU due to the uncertainties in the science and the economics. Regardless of the ability of policy-makers to reach such an agreement at this time, our approach of gaining information and making policy through a sequential decision-making framework is still valid.

[37] For the purposes of this stylized example, we will consider only the effects associated with the level of climate change and assume that effects associated with the *rate* of climate change do not vary among any possible emissions path to the stabilization goal. A similar, but more complicated, analysis would apply in the presence of uncertainty. One could imagine the following regimen: The world would agree, based on the currently available science, on a level of concentrations acceptable for 2100, and each country would be

This is not the occasion to present the mathematics of the solution, but the underlying principles are straightforward. The marginal cost (taking into account the time value of money) of reducing a given level of emissions should be the same every period. Higher level of emission reductions today reduce the amount of required emission reductions later, and the marginal costs of the timing alternatives (reduce today vs. reduce tomorrow) must be compared. Clearly, those reductions that involve zero costs today (the no-regrets policies) should be undertaken.[38] But the solution will involve going beyond that. How far beyond depends on several factors, such as how substitutability evolves over time (e.g., how easy it is to substitute non-emitting technologies for emitting technologies, and to substitute low-energy-intensive commodities for high-energy-intensive commodities, at different points in time) and innovation (investments in new technology may lower the marginal costs of lowering emission levels in the future).

One could, in principle, even decentralize the process, which can be seen under the overly simplified assumption that achieving a certain level of concentration entails "adding" certain amounts of carbon dioxide to the atmosphere. Each country could be given an entitlement, and each country would figure out for itself the best way of achieving that *concentration* target. Global public policy would simply focus on the issue of what the magnitude of those entitlements should be, how they should be distributed, and what should happen to those who violate the targets. The issue of short-run *emission* "targets" would simply not arise. More explicitly, the question of timing with regard to emission reductions would be moot.

<u>Enforcement and Time-Consistent Policy</u>

This system of entitlements would allow for the attainment of a concentration goal at least cost because it would provide for explicit inter-temporal trading of emissions (and, assuming a concurrent trading regime on a global scale, international trading as well). However, this approach presumes that countries would ensure that their cumulative emissions were consistent with their ultimate concentration goal. Consider a scenario in which a least-cost emissions path to a stabilization goal resembles something like the emissions pathways established by Wigley, Richels, and Edmonds (1996; hereafter WRE).[39] Successful implementation of a WRE-like path would require small emissions reductions in the near term, with large emissions cuts 50 to 75 years from now.

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allocated its "concentration contribution allowance." The overall target would be altered as new information arrived, with allowances increased or decreased accordingly. Prices for emissions would change over time, and insurance markets could develop. Well-functioning markets could efficiently address the inter-temporal efficiency problem, which would include the efficient bearing of risk.

[38] The appendix discusses how the scope of no-regrets policies should be expanded.

[39] WRE developed their emissions pathways as lower-cost alternatives to the emissions path scenarios developed by the IPCC (1994) for various stabilization targets (WG-I pathways). Through the Stanford Energy Modeling Forum, six additional modeling teams evaluated the costs of achieving a 550 ppm stabilization target via the WG-I emissions path and the WRE emissions path. On average, these modeling teams found that the WRE path to 550 ppm would have one-third the costs than the WG-I path to a 550 ppm concentration goal (Weyant 1997).

The very modest abatement effort in the near term under the WRE-like scenario raises questions about the political credibility and inter-generational equity of such a policy.[40] As the time for larger emissions cuts approaches, policymakers who may not have even been alive at the time of an agreement for the WRE-like path may not feel beholden to this agreement. A country that postpones emission reductions today, claiming that it will make up for them later, would later be confronted with an impossible task, and therefore, would not be forced to meet its commitment. Fundamentally, it is not sufficient to devise the economically optimal path, if that path has zero probability of being implemented in the real world.

A related issue involves internal political dynamics within a country. It is impossible today to commit policy-makers in the future to a specific course of action. Policy-makers may therefore want to alter the incentives facing future policy-makers (who may have different preferences), by changing the tradeoffs involved in addressing climate change. For example, more aggressive action today (relative to the economically optimal path) would inefficiently add to the economic burden today while reducing the burden tomorrow. But such an inter-temporal trade may carry an important benefit: By reducing future costs, policy-makers today may be able to increase the likelihood that future policy-makers (with potentially different preferences) will actually continue the effort to address climate change rather than abandoning it.

These dynamic consistency issues bring us back to emissions targets, and thus the timing of such targets. The only way to ensure long-run compliance with a commitment to a given stock entitlement in the long run is to enforce reductions in emission flows in the meantime. The question of setting targets, from this perspective, entails setting *minimum* levels of reductions such that, given the probability distribution of reductions that would eventually appear to be desirable, a high likelihood of "dynamic consistency" exists. That is, given the emission reductions that have already occurred, the costs of obtaining the eventual target are within the politically feasible set.[41]

Issues of dynamic consistency are also important in the context of investments, and particularly investments in innovation. They thus affect the setting of emission targets, especially within a bankable permit system. The prices of emission permits that prevail today will depend on beliefs about the stringency and enforcement of commitments in the future. Commitments in the future will affect behavior today only if it is believed that those commitments will be enforced. But if the commitments are such

[40] Inter-generational equity issues arise if intervening generations consume, rather than save, the resources that would have otherwise been devoted to addressing climate change. In that case, future generations are left with a larger burden in terms of emission reductions (relative to an alternative in which the reductions occur earlier) without any additional resources (as would have been accumulated through higher saving) to meet the costs of such reductions.

[41] This formulation makes clear that the setting of the target today depends on (a) *a priori* judgments concerning the eventual concentration levels that will be desired, as more information becomes available; (b) political economy concerns (such as the magnitudes of costs above which it will be difficult to obtain agreement on emission reductions); and (c) the frequency of revision (more frequent revision of targets, as information becomes available, reduces the consequences of setting too low a target today).

as to impose what may be unbearable costs in the future, they will not likely be enforced; the lack of credibility in enforcing the commitments will then attenuate incentives to innovate. In this sense, it is not obvious that increasing the magnitude of future commitments necessarily leads to faster innovation, at least beyond some level. The difficulty is that it is hard to assess now the nature of beliefs about future enforcement, because they are partly predicated on political processes. Currently, any commitments have less credibility than they otherwise would, simply because the United States refuses to ratify its Kyoto commitments. Given that refusal, global incentives to innovate are reduced. Alternative, but more credible, frameworks could thus succeed in achieving higher levels of emission reductions even if they entail seemingly setting lower "commitments."

These dynamic consistency concerns highlight the importance of two issues that we address in subsequent sections: the political economy issues associated with reaching consensus and the enforcement mechanism in an international climate treaty. The enforcement mechanism is crucial to the effectiveness of any international effort to reduce emissions. If there is a cost to reducing emissions, but no enforcement mechanism, each country would have an incentive to be a free rider because the atmosphere is a global public good. Furthermore, the costs of compliance within countries may be concentrated in certain industries, who will therefore constitute a strong interest group to block emission reductions even when the country as a whole (as well as the world as a whole) benefits. Thus, some mechanism must exist to induce countries whose internal political dynamics may militate against complying to do so.

These are classic public goods and public finance issues -- with one major difference. The difference arises from the absence of a global government with the power to enforce international agreements. Nonetheless, the issue of achieving cooperative outcomes in non-cooperative games has been widely studied, and some of the insights from that literature can be applied to the issue at hand.

Credible enforcement is so central to any international effort on climate change that it is worth exploring how to bolster the effectiveness of the enforcement mechanism even before examining different approaches to emission reductions. Given the limitations imposed by national sovereignty, the question is what kinds of sanctions the world can impose on a "renegade" country that refuses to comply with international norms. Both social and economic sanctions are possible.

Social Sanctions

Social sanctions may include disbarring the country from participation in international activities such as the Olympic games, voting against the country having a seat on certain committees in international organizations, or other steps.

An alternative strategy would be to enlist civil society in a massive boycott of the rogue country's products (especially those products responsible for high levels of emissions). Ostracism has long been a sanction employed against those who refuse to comply with international social norms.[42]

Economic Sanctions

The major economic sanctions are associated with trade, and although trade sanctions are often ineffective when imposed by a single country against another, they can be effective in some limited situations.[43] Trade sanctions were part of the backdrop to the Montreal Protocol to protect the stratospheric ozone layer, although compliance has been achieved without resorting to them.

A question remains about how such trade sanctions can be squared with World Trade Organization (WTO) obligations. In particular, it is unclear what happens when two international treaties come into conflict. In the following paragraphs, we describe how a sanction system could potentially work, and how it could respond to a situation in which WTO obligations were found to be inconsistent with climate treaty obligations.

The easiest context for seeing how an international compliance regime would work is if the global agreement involved common measures (e.g., a carbon tax). If one country refused to comply with that approach, the rest of the world could simply impose a compensating tax on the relevant nation's exports. Indeed, the other nations could impose a *punitive* carbon tax -- i.e., a tax against the rogue nation's exports equal to, say, three times the carbon tax that would have had to have been paid in the first place.[44] The tax could even vary with the ratio of exports to domestic production, so that the total carbon tax collections collected from the country by foreign governments would be a fixed multiple of what the country would have collected itself, had it imposed the carbon tax.[45] Such a system could change the political economy of the underlying agreement, since the interests who previously opposed the imposition of a carbon tax domestically would have less incentive to continue such opposition.[46]

The hardest questions are posed by potential WTO restrictions. The traditional interpretation of WTO rules is that they do not allow discrimination on the basis of process and production methods. This interpretation would preclude taxes based on energy or greenhouse gas inputs. The recent shrimp-turtle case, however, raises

[42] Another strategy being explored by environmental law groups involves class action suits filed in domestic or international courts. See Seelye 2001.

[43] See Hufbauer, Schott, and Elliott 1990.

[44] Countries that failed to impose the carbon tax on the imports of commodities from the rogue country would themselves face taxes on their exports (and similarly for countries that failed to impose taxes on those who failed to punish rogue states).

[45] The proceeds of such fees could be contributed into a global carbon fund. It is important that the decision both to levy the carbon tax and to allocate the proceeds be international, so that the taint of hidden protectionism be avoided.

[46] In the case of a tradeable allowance scheme, a country that did not require its firms to have such permits could be treated as if it were *subsidizing* production. In effect, the nation would be treated as if it had given a resource to its domestic firms at a zero price. Other countries would then be allowed to impose countervailing duties on the nation's firms. This system could also encourage nations that did adopt a permit system to auction them, rather than allocate them for free.

interesting questions about the traditional interpretation of WTO rules. In the shrimp-turtle case,[47] the appellate body found that Article XX of the GATT 1994 in principle allowed countries to impose trade sanctions on the basis of environmental concerns outside their borders (in this case, shrimp caught outside the United States in a manner that incidentally killed sea turtles).[48] The logic of the appellate body's argument could easily be extended to allowing nations to impose trade sanctions on rogue countries that do not obey international climate norms.[49]

Regardless of whether WTO regulations *allow* such trade sanctions, they do not *forbid* them: they only allow retaliation against countries that impose sanctions outside the WTO rules. Thus, the countries of the world could impose sanctions against a rogue nation, knowing that the rogue nation may be entitled under the WTO rules to retaliate. Such retaliation may not be undertaken in any case, since it would only serve to reinforce opposition to the rogue nation. Indeed, any such "trade war" could increase public sentiment for compliance with global norms. The danger with this approach, however, is that excessive reliance on trade sanctions may undermine the general WTO framework and threaten global trade.

Carrots for Compliance

Another approach, which could complement the trade sanctions approach, would provide positive incentives for compliance. Such carrots could easily be introduced for developing countries, simply by providing assistance for enhancements to energy efficiency (as under the Global Environmental Facility), and, going further, by making international assistance conditional on reasonable compliance with whatever norms are established for developing countries (see below). In addition, the revenues from a carbon tax (or the sale of emission permits) could be used to provide "rewards" to countries that do best in improving energy efficiency or in reducing emissions -- a kind of contest structure, which has been shown to have strong marginal incentive effects.[50]

Indirect Incentives to Promote Compliance

Still other possibilities exist for encouraging rogue states to participate in a global consensus agreement. For example, by setting high standards for efficiency (e.g., for consumer goods like automobiles and refrigerators), the world could either force a rogue nation to go along with these standards or put the rogue nation's firms at a marked disadvantage in world markets (since they would not be able to export goods to countries with the standards). As one example, by specifying very high fuel efficiency standards, foreign nations could force American manufacturers to produce more fuel-efficient cars or to eschew export markets. Furthermore, American firms manufacturing cars abroad

[47] World Trade Organization 1998.
[48] Sands 2001.
[49] More generally, there is an increasing consensus behind the proposition that if WTO rules preclude the enforcement of sanctions associated with the failure to comply with international treaties, those WTO rules should be changed.
[50] See Nalebuff and Stiglitz 1983a, 1983b.

would have to develop energy-efficient models, and it is possible that such models would eventually make inroads in the United States.[51]

In summary, in a world in which there is no global government to enforce compliance, a variety of measures and strategies must be invoked to induce voluntary compliance by any state that chooses not to go along with global norms. With democratic nations, the most important part of any strategy may be political: to change the perceptions and interests of those within the rogue country to induce a change in policy.[52]

Developing Countries and "Dividing the Pie"

In addition to ensuring credible enforcement, any effort to reduce emissions must also address the question of who does them. Before examining the structure of the emission reduction framework, it is therefore important to consider the involvement of developing countries. Should developing countries play a commensurate role to developed countries, as suggested by the Byrd-Hagel resolution? How does one create the incentives for developing countries to undertake substantial emissions mitigation efforts? How can such a role influence the magnitude and timing of developed country efforts?

First, consider the current approach to allocating emissions "property rights." The Kyoto Protocol and (to a weaker extent) the FCCC reflect a belief that "property rights" in pollution should be assigned on the basis of previous levels of pollution, with slight adjustments for circumstances. The FCCC set goals based on 1990 emissions levels and the Kyoto Protocol defines emission limits in a similar manner, with some modest modifications. Thus countries that have reduced emissions substantially since 1990 -- and for whom further reductions would be all the more difficult, assuming an increasing marginal cost of reductions -- undertook obligations just as countries who had done little and for whom the cost of meeting the obligations would be small. Furthermore, countries with rapid economic growth since 1990 undertook similar obligations to those with slower growth, even though meeting the targets would be far harder for fast-growing countries than for those countries, like Russia, in which rapid economic decline since 1990 makes compliance a relatively easy matter. In short, virtually all the developed

[51] Another possibility is that the governments complying with an international climate agreement could undertake a cooperative venture together with business for emission-efficient research, with patent rights shared among the countries. Any rogue nation would thus be put at a distinct disadvantage -- it would either have to finance its own research program separately, or see its technologies grow increasingly outdated. (This strategy provides an example of a general principle in non-cooperative game theory: by increasing the range of punishments -- the set of activities from which a deviant can be precluded -- one can increase the range of cooperative activities that can be supported.)

[52] Although we have been concerned in this section with issues of compliance with an international agreement, it should be clear that similar issues affect the bargaining over an international agreement. To the extent that there is popular support in a specific country for an agreement, there will be pressure to go along with an international consensus. Similarly, to the extent that it appears that the country will have to pay a significant cost for not going along with an agreement, there will be pressure to participate in the agreement, to help shape it more in line with the country's interests and concerns.

countries (but one) overlooked their petty self-interests and the kind of fine-tuning that could well have been justified by broader principles in the name of undertaking an action that was viewed as in their collective interest.

The general principle of basing emission levels on historical patterns will not be easy to extend to the developing world, however. The principle of entitlement based on past emission levels will not work because emission levels in the developing countries were artificially constrained by their poverty and lack of income. The question then becomes what could serve as an acceptable alternative principle. Two possibilities have been discussed: per capita pollution limits and per GDP pollution limits.

Emissions based on population

Per capita limits would simply define a nation's emission limit as some internationally chosen amount per capita, multiplied by the number of citizens in the country. From a strictly ethical perspective, this approach seems defensible. But several problems arise in the context of such an approach, some of which could be easily addressed, others of which would be a source of continuing concern.

One problem is that if the developing countries were given the same per capita emission allowance as the United States, a long lag would arise before such limits would become binding on them. Conversely, a per capita standard would imply large emission reduction burdens for the developed countries. Countries such as the United States, Canada, and Australia have per capita carbon dioxide emissions that are four to five times the global average. Since it seems unlikely that these countries could attempt to reduce emissions by 70 to 80 percent, a viable per capita quota approach would likely involve an international trading scheme. However, this raises the concern that if an international trading scheme is inefficient, the costs of achieving a given global emissions target for a specified period of time would be much higher than necessary.[53]

The second problem is that this criterion does not punish countries that fail to control their rate of population increase; indeed, it effectively "rewards" them by giving them an extra entitlement to emissions.[54] This problem, however, can be addressed in a straight-forward manner: Entitlements can simply be based on population levels as of some historical period.

The third problem with a per capita standard is that it would give a large share of the permits to a very small number of countries: For example, India and China would receive about 38 percent of all greenhouse gas emissions quota under a per capita system.

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[53] The nature of the original allocation matters when transaction costs inhibit the trading system. The greater the difference between the original allocation of tradable quotas and what would be the efficient equilibrium re-allocation of permits after trading, the higher the costs would be in the presence of transaction costs (Stavins 1995).

[54] If the total aggregate emission level is capped, an unanticipated increase in population must trigger a reduction in the global per capita emission level. Thus the additional emissions from the country with the population increase must come at the expense of others, including those who have taken an active role in controlling population.

With 38 percent of the emissions quotas (and only about 15 percent of the world's carbon dioxide emissions), these two countries could also act to influence the price of tradable emission quotas. With the value of emission quotas likely to be in the tens to hundreds of billions of dollars, it would not be prudent to develop a climate policy with significant economic incentive for two countries to collude to maintain an inefficiently high price for tradable quotas.

The fourth set of problems is associated with the fact that a uniform per capita allowance does not reflect the circumstances of different countries: citizens of colder countries need more energy to keep their houses warm; citizens of hotter countries need more energy to keep their houses cool; countries in which population is sparsely located need more energy for transportation; countries with higher per capita incomes need more energy to produce their higher levels of GDP; countries that are poorer cannot afford the most energy efficient technologies. Although one would be ethically justified in adapting the per capita allowance to these differences in circumstances, it would be problematic to reach a consensus on the magnitude of the adjustments. In other words, there are no obvious ethical principles to guide the magnitude of the adjustments, and self-interest is likely to dominate the discussions. (That is presumably why, under the Kyoto Protocol, no such adjustments were made, at least on a systematic basis.)

Emissions based on GDP

A second approach endows the "right" to pollute based not on the population of a country, but rather on its GDP.[55] Under this approach, countries that produce more have proportionately more "rights" to pollute. This approach has a practical advantage: it does not put developing countries at a disadvantage (as would a system of assigning emission commitments based on past levels of emission), nor does it leave them almost free of commitments (as they would be for the immediate future if a per capita emission constraint were put into place).

The developing countries have higher levels of emission per dollar of GDP than the developed world, but much lower levels of emissions per capita. Hence, a system in which they would make commitments to reduce commitments per unit of GDP at a particular rate would encourage efficiency, but impose no constraint on growth (other than the constraint that higher investments in increased energy efficiency and lower emissions per unit of energy would impose).

Such a system would have a further advantage over one based on meeting some historical emission level: Whether a country meets an historical emission commitment depends as much, or more, on how well it manages its overall economy rather than its efforts at reducing emissions. Those countries that experience poor macroeconomic performance find it easier to meet their emission targets; those counties with a good record of macroeconomic management (or good luck) find it much more difficult to meet

[55] As with the per capita system, an international trading regime could be introduced within this framework to ensure global efficiency.

their requirements. To some degree, these outcomes are desirable: Greenhouse gas commitments under such a system provide some "insurance" against bad economic outcomes, and countries that have experienced more rapid growth tend to have more resources to invest in emission reductions. But it is probably far from the optimal insurance scheme. If there were convergence in growth rates and if all targets were long run,[56] this flaw in the current system would perhaps not be too serious; since convergence is slow (if it exists at all), and since targets have been set with relatively short horizons, the concerns loom somewhat larger. A per unit GDP target would avoid these issues.

As with the per capita target, one criticism of the per unit GDP target is that it fails to reflect the different circumstances of countries. But the system could be adjusted to reflect various factors. For example, countries with lower initial efficiency levels could be required to meet larger percentage increases in energy efficiency.

Political viability of alternative targets

Since emission rights are valuable, the rules for granting them have substantial distributional implications. The developing countries clearly benefit from a per capita principle relative to a per GDP principle; the U.S. benefits from the converse. If the governments choose to sell those rights internally, the *net* burden is likely to be small, and possibly negative (at least in some countries); and the absolute differences in net burdens across countries may be even smaller. The revenues generated from the sale can be used to reduce other distortionary taxes, and hence the net effect is equivalent to the difference between two Harberger triangles (the implicit one associated with the implicit tax on emissions, minus the one associated with the tax reduction). Still, countries facing larger emission reductions will face larger internal dislocations, and hence, potentially, will face more substantial domestic opposition.

The political viability of the international agreement will depend in part on how governments manage the distribution of burdens internally. The distributional impacts may be reduced, for instance, by providing pollution rights related to past levels of emissions; but doing so restricts the ability of governments to use the revenues from the sale of emission rights to reduce distortionary taxes or to offset the regressivity of an emissions tax. In principle, if emitters are compensated by the granting of emission rights, their opposition should be limited, because the *net* cost imposed on them will be limited. Some firms may also realize that in general equilibrium, the net costs will be far less than in partial equilibrium, because any additional costs will be reflected in prices; indeed, profits in some non-competitive industries may actually rise. Nonetheless, industry groups as a whole are likely to oppose the effort, even if the net costs are small. Given this likely opposition, it may be better *even from a political perspective* (let alone an economic one) to sell the emission rights, using the proceeds to finance tax reductions that could enlist broader popular support.

It is important to note that developing countries have presented their perspective on fairness: They have argued that the problem of climate change primarily involves

[56] The same result would obtain if emission allowances were bankable.

stocks or concentrations of greenhouse gases in the atmosphere. Hence, if there is a danger associated with increases in greenhouse gases above the natural baseline, the right to add to that stock should be allocated uniformly among all those in the world. The developed countries have already contributed much to the stock of greenhouse gases, the argument continues. The developing countries should, in this view, have the right to contribute the same amount to the stock, which would imply much larger emission allowances for the developing countries than for the developed economies in the future. Although there is merit in this focus on concentrations, it puts the developed countries at a disadvantage: they are, in effect, being punished for contributions to pollution that occurred before it was known that greenhouse gases involved negative environmental externalities, and therefore before appropriate incentive schemes to deter pollution could reasonably have been put into place. In any case, the approach would not be acceptable to the developed economies.

III. Uncertainty, Irreversibility, and Sequential Decision-Making

Underlying the process of building a global consensus on global warming has been the commitment that policies be based on the best available science. The scientific evidence of a threat from global warming is now accepted in almost all circles. Yet the science is also uncertain: we do not know precisely the consequences of increased carbon dioxide concentrations (or of particular policies designed to reduce emissions). We also do not know precisely the economic costs of increased emissions or the costs or effectiveness of measures designed to reduce those emissions (or to adapt to global warming). But the fact that there is uncertainty does not mean that we should simply wait and see. Rather, a rich literature in economics has developed on how to address policy decisions under uncertainty, especially in the context of potentially irreversible events, such as global climate change. Indeed, climate change was first mentioned in this literature some 27 years ago in a seminal paper by Ken Arrow and Anthony Fisher.

Sequential Decision-making

Over the past fifty years, a widely accepted approach to decision-making under uncertainty has developed. The approach involves a process of sequential decision-making, which explicitly takes into account the risks associated with alternative strategies, including irreversibilities and information that may subsequently become available. It lays out a plan of how actions will change as new information becomes available. It simultaneously calculates the value of information; investments in information acquisition become an explicit part of the strategy. (Such a framework underlay the discussions of the IPCC Working Part Group III, which concluded strongly that, on the basis of available evidence, it was worthwhile going beyond no-regrets policies.)

Within the sequential decision-making framework, the question of how fast emission reductions should be achieved is not the appropriate question. Rather, the appropriate question is what actions should be taken now. To be sure, if the set of actions that one had at one’s disposal were limited to “binding commitments to reduce greenhouse gas emissions," then timing would be the sole question. But one of the insights of modern decision-making theory is the recognition that alternative policy frameworks can greatly reduce risk, and that there are large welfare benefits from such a reduction in risk.

If it were possible to agree on targets and make them enforceable, the targets approach (as embodied in the Kyoto Protocol) would reduce the risks associated with global warming, but increase the risks (relative to other policies described below) associated with mitigation, because the costs of meeting the specified reduction target may be higher than expected. Within a sequential decision-making framework, such an allocation of risk burden would almost surely not be efficient. Consider, for example, an alternative framework in which one learns more about the short-run marginal costs of achieving a target before one sets a long-run binding target. Currently, we do not know the marginal costs associated with different reductions in emission levels. We have estimates, but as noted above, they vary widely in magnitude. An effective tradable quota scheme under a moderate target would reveal information about the marginal costs at that moderate target, which would be relevant for resetting the target. In the presence of uncertainty about the price of meeting a particular quota, a rigid quota can itself impose substantial risks. That is one of the fundamental flaws in the Kyoto approach.

<u>Criticisms of the Kyoto Protocol</u>

Some analysts have criticized the Kyoto Protocol as requiring inefficiently rapid reductions in emissions. We do not share that view: If the Kyoto targets could be implemented within an efficient and *global* trading regime, the expected costs would be moderate. Nonetheless, the Kyoto Protocol does suffer from structural flaws. As noted above, the social welfare costs associated with inter-temporally rigid policy responses (such as the Kyoto Protocol) in the face of uncertainty are real, and represent one of the impediments to achieving a consensus on what to do about global warming. In other words, and as discussed further below, the Kyoto treaty's quantity-based approach to emission reductions may involve moderate *expected* costs -- but unnecessarily high *risks* in the presence of uncertainty about those costs. If the assumptions upon which the expected cost estimates are based turn out to be incorrect, the Kyoto approach could prove unfortunate relative to an alternative approach that has the same expected cost but handles uncertainty more efficiently.

The other two shortcomings of the Kyoto approach involve distributional and effectiveness issues.

- *Distribution of costs and benefits*. Avoiding global warming is a global public good, requiring global collective action. In the face of such a public good, the key issue is who bears the costs of providing it. Although all countries will be affected by climate change, some will be more adversely affected than others; some may even benefit from climate change; and some may bear a disproportionate share of any mitigation costs. In the face of this distribution, the Kyoto Protocol adopts a somewhat controversial initial approach to the costs of reducing emissions. At least for the immediate future, it differentiates the obligations to be imposed on different sets of countries, recognizing that the developing countries have historically polluted less than the developed countries and that the developing economies may find it more difficult to bear the costs of reducing energy utilization and converting to non-carbon forms of energy. Thus, the Kyoto Protocol imposes binding commitments on the more developed countries over the next decade, but not on the less developed countries.[57] We return below to alternative ways of involving the developing countries in the effort to reduce emissions.

- *Enforcement*. Those who are asked to bear the costs of emission reductions will be willing to do so only if they believe that the regime is effective. An effective agreement requires enforceable obligations. To be sure, many countries will naturally view any enforceable obligations as an intrusion on their sovereignty. The section above examines alternative ways of bolstering compliance with an international agreement.

These issues are interrelated. Given the real costs associated with risk-bearing, a framework that imposes undue risks in reducing emissions is less likely to induce voluntary compliance. But designing effective enforcement mechanisms that can be imposed even on those who do not sign the treaty may change the economic calculus of participating.

The bottom line is that the Kyoto Protocol needs to be modified to reflect a more realistic set of political economy constraints. Although changes are needed, the general effort should not be abandoned. To be sure, uncertainty exists about the magnitude of the environmental effects and the economic costs of mitigating climate change. But in our judgement, the evidence suggests that it would be prudent to go beyond no-regrets policies. That is, given the magnitude of the risks and the long lags involved in changing total concentration levels, any reasonable degree of risk aversion implies that we should go beyond measures which, should it turn out that there climate change involves no economic or social costs (a highly unlikely event), we would not have regretted undertaking anyway. We therefore turn, in the next section, to a commonly proposed alternative to Kyoto (involving common measures) and then to our preferred approach to addressing climate change (involving a hybrid price-quantity system).

<u>One alternative to Kyoto: Common measures</u>

[57] This provision may seem reasonable from an ethical perspective, but it does undermine the effectiveness of the agreement. Without binding commitments from the developing countries, substantial "leakages" would exist in the compliance regime. Furthermore, in the absence of binding limits on developing country emissions, emission reductions in the developed countries could deliver less than expected climate benefits: For example, given the differences in binding limits on emissions, energy-intensive industries may be induced to migrate to developing countries. Emissions in developing countries would then exceed what had been projected under business-as-usual prior to the implementation of emissions abatement policies in developed countries. As a result, the increase in developing countries' emissions would offset some of the emissions reductions in developed countries.

One alternative approach to the Kyoto Protocol involves reducing greenhouse gas emissions through common measures. Thus, for example, all countries could impose a common tax on carbon emissions.[58] With all countries facing the same price of emissions, a carbon tax would ensure that emissions abatement occurs at least cost.[59] (This conclusion presumes that all countries adequately implement and enforce the tax and the transaction costs associated with complying with a tax are fairly uniform.[60])

The choice between the tax and the targets approach parallels the widely discussed choice between prices and quantities, which has been extensively discussed in the economics literature. In the absence of uncertainty (and ignoring distributional concerns), the two are equivalent. With uncertainty, the two can be markedly different. A tax provides insurance against excessive mitigation costs, by imposing a maximum marginal cost for such efforts. But it does not balance those risks against the risks of insufficient emission reductions. A target, on the other hand, provides insurance against insufficient emission reductions, but does not balance those risks against the risks of excessive cost. (A quantity-based emissions reduction effort effectively involves a "pay any price" approach to achieving those reductions, which raises the possibility that the costs of emission reductions exceed the benefits.) In other words, with a price measure, there is uncertainty about the level of emissions, and the environment bears the risk; with the quantity measure, there is uncertainty about the cost of compliance, and so firms and households bear the risk. Which is preferable depends on the sources of uncertainty and the degrees of income and environmental risk aversion.

This classical distinction between a price-based and quantity-based system becomes much less important in the context of sequential decision-making. Under a quantity system, the price of compliance will be revealed in a sequential framework; such information can then be used to reset the quantity targets. Under a price system, on the other hand, the quantity of emissions will be revealed; that information can be used to reset the price. The general point is that if the parameters can be updated regularly, as under a sequential decision-making approach, the distinction between a price-based system and a quantity-based system is attenuated.

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58 There are other examples of common measure approaches. The countries of the world could agree, for instance, on what are acceptable technologies. They could agree on CAFE standards for cars, or energy efficient standards for energy production, or for energy using technologies (e.g., light bulbs.) An alternative to a carbon tax, examined below in the context of uncertainty, involves a hybrid international permit system with a single capped price on the permits.

59 See, for example, Cooper (1998). As noted in the text above, advocates of carbon taxes also note that by taxing a "bad," governments can reduce taxes on "goods," such as labor and income. The net burden of the tax is thus smaller than it would otherwise be, since there is an offsetting reduction in distortionary taxes. Indeed, the net efficiency cost in most cases will be quite modest. In some countries, where energy is undertaxed (e.g., because of the influence of special interest groups) and other sectors are overtaxed, the net cost may even be negative, creating the so-called "double dividend" from environmental taxation. This same result obtains under a quota system if the quotas are auctioned and the revenue is used to finance reductions in other taxes.

60 This is simply the same transaction costs issue as discussed above with respect to trading under a permit system.

Given adjustment costs and therefore an optimal interval between adjustments, however, there remains some differences between the price- and quantity-based systems even under a sequential decision-making approach. In general, given these differences, it is better to have a mixed system (a non-linear price system, of which fixed targets can be thought of as a limiting case), rather than either a pure price-based system or pure quantity-based system. In the following section, we describe a practical form such a mixed system can take. Although we describe the mixed system as putting price caps on quantities, there are alternative versions of mixed systems that entail putting a quantitative cap on a price system. The latter is likely to be much more difficult to implement.

An Alternative Approach: A Hybrid System

This section explores our preferred approach to addressing the uncertainty surrounding the economics and science of climate change, encouraging participation by developing countries, and attenuating concerns about enforcement.

The most auspicious approach to balancing the various uncertainties involved and promoting the political viability of the emission reduction effort combines a tradable emission permits with a cap on the permit price.[61] For many types of environmental problems, academic research from the 1970s suggested that such a hybrid permit approach would combine the best features of an emissions tax and a pure permit system. More recent research by Resources for the Future suggests that a combined system for greenhouse gases may be more economically efficient than a simple permit system.

Under such a combined or hybrid system, sometimes called a "safety valve," a base level of emissions permits would be auctioned.[62] The twist would be that governments would also stand ready to sell additional permits at some given price. Sales of such additional permits would ensure that the market price of the permits never exceeds the governmental price. To be sure, any additional permit sales would allow more emissions, undermining the environmental integrity of the system. The goal, however, should not be to reduce emissions regardless of the cost. The combined system allows policy-makers to balance economic and environmental interests and uncertainties in a manner not possible under a pure price-based or pure quantity-based systems.

One of the principal benefits of this approach is its flexibility, which is crucial to addressing uncertainty. The design itself reflects a balance between the uncertainties surrounding mitigation costs and environmental benefits. Furthermore, adjustments in both the limit price and the targets could be made as information on the costs of global warming and the costs of emission reductions becomes available, thus allowing this approach to incorporate new information as it arrives. To be sure, the adjustments must

[61] Pizer 1999. For another interesting hybrid system, see McKibbin 2000.

[62] Whether the permits are auctioned or allocated administratively is an extremely important political and economic issue. We strongly favor an auction. For an introduction to the arguments in favor of auctioning the permits in the context of the United States, see Americans for Equitable Climate Solutions, "The Sky Trust Proposal to Reduce U.S. Carbon Emissions," available at www.aecs-inc.org.

be made in a manner that also reflects political economy considerations – the socially optimal path for the limit price may not be politically feasible. The key challenge is to come as close as possible to the optimal path given political economy constraints.

The approach has several crucial political economy advantages. For example, it would simultaneously cap compliance costs and the value of the entitlements, and thus reduce the distributional controversies associated with the granting of the entitlements. A guaranteed price cap would also force each side in the climate debate to back its convictions with a bet.

Assume, for example, that the price for additional permits were initially set at $30 per ton. (The $30 figure is for illustrative purposes. If the combined system were adopted, the appropriate trigger price would become a key element of the debate, and the price could evolve over time.) According to some environmental groups, no one would buy permits from the government at $30, since their analyses suggest that the market cost of regular permits would always be lower. But if industry estimates turned out to be right and the costs were higher, additional permits could be purchased from the government at $30 -- thereby increasing the supply of permits and providing protection for firms and consumers. In this case, a combined system could bolster the political viability of the greenhouse gas reduction effort by eliminating the fear of excessively high costs that is likely to derail any serious effort to reduce emissions.[63]

It is worth emphasizing that the safety valve is *not* intended to set an inefficiently low carbon price over time. Indeed, the safety valve may allow a *higher* price of carbon than would otherwise be the case, because it provides assurance that the costs will not exceed that level. Risk-averse households and firms may therefore be willing to tolerate a higher price for carbon under the safety valve approach than they would be willing to tolerate under a pure quantity-based approach. That is, the trigger price under the safety valve could be set slightly above the *expected* price under a quantity-based approach – and those who are risk averse with regard to the emission reduction cost should still prefer the safety valve system to the alternative. The cost insurance provided by the safety valve could thus have environmental benefits, once the political economy of the emission reduction effort is taken into account. In any case, the system is not intended – at least in our view – to limit the price of carbon and therefore emission reductions inefficiently.

This approach could be implemented either individually by each nation,[64] or collectively by the world. In the latter case, an international authority would be created that could create additional emission permits at a particular price. The proceeds from the

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[63] The hybrid system may also have another political economy benefit relative to a pure price-based system (albeit not relative to a pure quantity-based system): Auctioned permits may not be viewed in the same manner as a "tax," whatever their economic effects. In the United States at least, auctioned permits may be more politically acceptable than an explicit tax.

[64] That is, in a world with tradeable permits, the government of a country could, in effect, *insure* those in the country by agreeing to purchase permits abroad and resell them at the fixed price. The country as a whole would have to bear the risk, but individual firms would not, and this could make a difference for the political support behind the system.

sale could be used to finance research on global emissions and to help poorer countries meet their obligations.

The approach could, and should, incorporate developing countries. The quantity component of the system for developing countries could take the form of a carbon-to-GDP ratio,[65] a per capita carbon allowance, or a target indexed to various economic indicators.[66] To be sure, it may be difficult to convince some developing countries to adopt such a commitment. For example, although the option for developing countries to adopt emissions targets voluntarily was considered in the Kyoto negotiations, it failed to achieve consensus on the last day. Nonetheless, we believe that all countries should participate in the production of a global good.[67]

If necessary, the near-term commitment for developing countries could be voluntary (despite the problems associated with such voluntary commitments explained above), with a mandatory commitment binding in the medium-term. Such a voluntary approach -- which would allow developing countries to assume commitments that could vary in form -- would be less desirable than a universal approach. But it would still be valuable in providing information about how emissions commitments interact with economic development, the primary concern for these countries. This kind of information would be useful for negotiations over binding, medium-term commitments for all countries to undertake emissions abatement efforts.

The economic incentive for developing countries to adopt commitments could be two-fold. First, they could take on emissions commitments less stringent than the OECD countries, and then, under a functioning international trading system, sell emissions allowances to other countries. Second, as we note above, funds from the sale of extra emissions allowances at the price cap could be provided to participating developing countries to assist them in their emissions abatement efforts. For example, the share of the funds a developing country could receive could be proportional to the level of its emissions abatement. The system would also need a mechanism for ensuring enforcement. We would advocate experimentation with the different forms of enforcement mentioned above.

The approach does not necessarily involve global emission reductions that are less aggressive than embodied in the Kyoto Protocol. Assume, for example, a trigger price of $30. Many estimates of emission costs under the Kyoto Protocol with international

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[65] Baumert et al 1999.

[66] Lutter 2000.

[67] Developing countries' risk aversion may be larger, and thus their willingness to bear risks lower, than the developed countries. Hence they would prefer to have a lower price on the safety valve. For most developing countries, however, this factor may be dominated by the expected transfer from a higher price: they are likely to be selling emission rights rather than buying them, and hence are better off the higher the price. Nonetheless, to provide some insurance against excessive costs for developing (or other) countries, the international community could create a flexible price schedule. Countries that emit beyond their allowance could, in some situations, be allowed to purchase emission rights at a discount. Such a scheme would imply inefficienciesin emission reductions, but may be necessary to achieve international agreement on the approach.

trading – including those published by the Clinton Administration – reflected central cost estimates below that trigger level. The implication is that the emission reductions achieved would be expected to be at least as large as those embodied in the Kyoto Protocol. The key difference is what happens if the assumptions underlying the cost estimates (such as a fully efficient international trading regime) turn out to be incorrect.

Furthermore, it is important to note that this proposal does not necessarily represent a substantial change from the current international climate policy architecture under the Kyoto Protocol. Indeed, some countries considered the possibility of a financial penalty through the compliance mechanism prior to the Hague conference, which could be implemented in a fashion akin to the safety valve.

There is a compelling argument for approaches that can be viewed as *modifications* (even if fundamental in nature) of the Kyoto regime rather than as a new regime: the international community has invested substantial resources in consensus-building around the Kyoto-approach. Given the complexity of arriving at a compromise, it makes sense to begin from a point of general agreement. We believe that the basic approach of this section could be implemented without jettisoning the entire Kyoto Protocol, which substantially bolsters the real-world viability of the proposal.

Other variations around the safety-valve theme focus more on uncertainties associated with the instruments used to reduce emissions. Some countries may make good-faith efforts to comply with targets, and yet fail to do so, either because GDP has increased faster than expected, or because private sector responses have been less than expected. To address these concerns, countries that implement a set of commonly agreed measures (such as emissions taxes) could be given a safe harbor, that is, treated as if they were in compliance. Such an approach would reduce the risk facing participating countries, and provide an added incentive to take relatively strong measures soon.

It is also worth considering the timing of when to implement the basic approach. Put simply, we favor immediate action. In particular, although policymakers are forced to make decisions under uncertainty, they can undertake actions that help reduce this uncertainty. In particular, pursuing some emissions abatement policies *now* allows policy-makers to learn more about the costs of emission reduction.[68]

Fundamentally, the approaches discussed in this section provide a flexible framework for addressing the uncertainty surrounding climate change economies and science, as well as distributional issues. In effect, the system could evolve into either a global carbon tax or into a global emission targets regime. We remain quite enthusiastic about the hybrid approach as a practical response to both the economic and political challenges involved in addressing climate change.[69]

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[68] See the references and discussion in Dixit and Pindyck 1994, pp. 345-356.

[69] Another approach to the problem of uncertainty would be to provide insurance – in effect, emitting countries that believe strongly that there is no problem associated with climate change could insure the countries that are likely to be adversely affected, and the premium which they would charge would be correspondingly small. To make such insurance "credible," funds would have to be set aside, and some

IV. Conclusions

This conference is primarily intended to examine the timing of emission reductions. But it is crucial to realize that such "timing issues" fundamentally reflect political economy constraints: In the absence of any political economy constraints, the optimal approach to climate change would involve a set of concentration targets that each nation was responsible to meet. Such a system would allow maximum inter-temporal and global flexibility in meeting the ultimate concentration target, obviating the need to discuss the "timing" of emission reductions in the short run.

The problem with such long-term concentration targets is that they are unlikely to be dynamically consistent: It would prove impossible to enforce the commitments until it was too late to undertake any significant corrective action. Such dynamic inconsistency brings our attention back to short-run emission targets and alternatives for reducing emissions. But a focus on dynamic consistency also forces us to focus on the political economy of global warming, which in turn necessitates a close look at issues of equity, particularly as perceived by developing countries, and enforcement. A viable regime for reducing global warming must have an effective system of enforcement (which almost surely will entail some form of trade sanctions, and some form of incentives), and must embrace the developing countries.

We conclude that the most auspicious approach to achieving emission reductions in the near-term is implementing a hybrid system of emission quotas with a maximum permit price. Such a policy reflects both environmental goals and economic concerns, by balancing the risks associated with climate change with the risks associated with excessively costly emission reductions. Perhaps more importantly, a hybrid system is likely to bolster the political viability of climate change measures, even in the United States, and could build upon the basic structure of the Kyoto Protocol.

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third-party enforcement (to ascertain whether compensation needs to be made) would need to be established. The potential magnitude of the damages is extremely large, so the amount of funds that would need to be set aside is correspondingly large. But the funds could be invested in a global environmental facility, with government guarantees, so that they would yield returns at least equal to the safe rate of return. Alternatively, those who believe that there is a need for emission reductions could provide insurance to those who are more skeptical that their investments in emission reductions would not be in vain, that is, that the global benefits from limiting greenhouse gas emissions are significant. Again, the cost of such insurance should be low, since there is a large group of those who believe that greenhouse gas accumulations are very likely to represent a problem. Again, to make such insurance credible, funds would need to be set aside, and again, the funds set aside can be used in the interim to improve greenhouse gas efficiency.

Appendix: Expanding the Scope of No-Regrets Policies

Although this paper is predicated on measures beyond no-regrets policies, the full scope of such no-regrets policies has yet to be explored. This appendix therefore briefly explores ways in which such policies could be strengthened, should a mandatory approach to emission reductions prove impossible to implement.

Much of the public discussion on no-regrets policies has focused on improvements in resource allocation resulting from eliminating energy subsidies. Even in the United States, subsidies for inefficient energy use are embedded in the tax code (e.g., through depletion allowances and a variety of tax subsidies). Within developing countries, the opportunities for such actions are even more significant. Some of the largest developing countries still maintain substantial energy subsidies that distort the allocation of resources in their economies and result in inefficient and excessive use of fossil fuels. In some cases, energy subsidies reflect explicit policy decisions on distributional grounds (e.g., low-price kerosene fuel in India for low-income households). However, in many other cases, energy subsidies reflect little more than state-sponsored support of industrial activity.

The International Energy Agency (1999) reviewed energy subsidies in eight developing and transition economies and found that some of the largest energy users among developing countries could reduce their carbon dioxide emissions by 15 to 20 percent by eliminating their energy subsidies. In doing so, these countries would also *raise* their gross domestic output by about one percent annually. Furthermore, some of these countries have serious local air pollution problems and would enjoy other economic gains through reduced particulate matter pollution.

Such steps should be taken. But the focus of no-regrets policies should also be expanded. To take but one arena, consider the automobile. Drivers do not currently pay for the marginal road congestion that they cause. Technologies now exist that could easily monitor road use and provide automatic billing. Automobile insurance could thus be based on the amount driven rather than just on the basis of accident histories; using both would provide a better estimate of the marginal accident externality. In 1967, Senator Daniel Patrick Moynihan suggested "pay at the pump" insurance, which would bundle auto insurance with payments for gasoline. In 1969, William Vickrey similarly proposed a surcharge on gas prices as a way to internalize the costs of auto accidents. Given technological developments and improvements in computer processing speeds, the idea is now feasible. Such a reform could improve the efficiency of the automobile insurance system while also reducing greenhouse gas emissions.[70]

Other market failures involve R & D, with inventors typically appropriating only a fraction of the social value of their contributions. In the presence of market mis-pricing -- such as when polluters are not charged for the marginal costs of their pollution -- the gap between the private and social return to innovation is even larger. Under current arrangements, there is very little incentive to reduce emissions, and therefore very little

[70] Edlin (1999)

incentive for innovations directed at reducing emissions. Even if one does not believe that the costs of climate change are high, the expected marginal cost is surely positive, and hence there should be *some* price associated with emissions.

Imperfections of information represent another market failure. Again, the failure to charge marginal social costs for emissions interacts with this market failure: no one has an incentive to disseminate information that would enable the reduction of emissions. Information costs involve largely up-front capital costs, and the willingness of the private sector to make these risky investments is impeded by other market failures, involving imperfect risk and capital markets.[71]

Finally, coordination failures impede efficiency. For example, energy-efficient light bulbs are not widely used, partly because builders will not install the sockets; and they will not install the sockets because the light bulbs are not readily available in stores; and they are not readily available in stores because there are few sockets designed for them. Collective action can be used to help address each of these market failures.

The fundamental conclusion is that nations could undertake a much broader array of "no regrets" policies. Implementation of such no-regrets policies can and should proceed independently of any international agreement to reduce greenhouse gas emissions.

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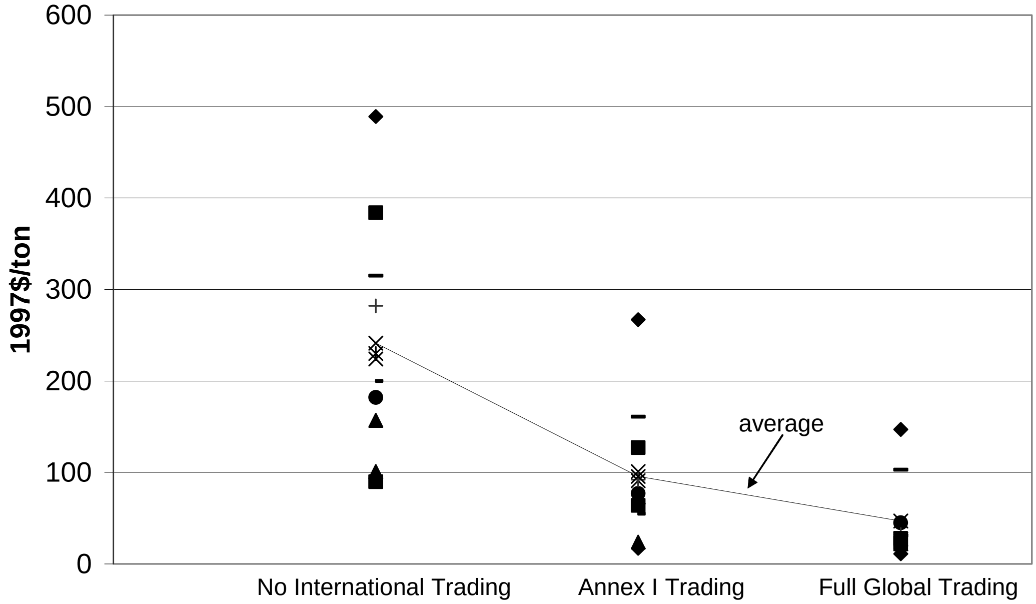
[71] The private costs of capital typically are higher than the social costs of capital (inter-temporal social prices), especially when there is credit rationing (Stiglitz and Weiss, 1981) and equity rationing (Greenwald, Stiglitz, and Weiss, 1984).

Table 1. EIA 2000 Carbon Dioxide Emissions Forecasts

Scenario	1999 CO_2 (MMTCE)	2010 CO_2 (MMTCE)	2020 CO_2 (MMTCE)	2000-2020 GDP Growth Rate	2020 World Oil Price (1999 $/bbl)
Base Case	1511	1809	2041	3.0 %	$22.41
High GDP Growth Case	1511	1883	2193	3.5 %	$22.41
Low GDP Growth Case	1511	1750	1916	2.5 %	$22.41
High Oil Price Case	1511	1804	2034	3.0 %	$28.42
Low Oil Price Case	1511	1819	2051	3.0 %	$15.10
2001 Technology Case	1511	1866	2157	3.0 %	$22.41
High Technology Case	1511	1734	1875	3.0 %	$22.41

Source: EIA 2000, Tables 19, 20, B19, C19, F5

Figure 1: U.S. Permit Prices Under Kyoto Protocol



Source: Stanford Energy Modeling Forum, Weyant and Hill 1999

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