Life After Kyoto: Alternative Approaches to Global Warming Policies

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Abstract

This study reviews different approaches to the political and economic control of global public goods like global warming. It compares quantity-oriented control mechanisms like the Kyoto Protocol with price-type control mechanisms such as internationally harmonized carbon taxes. The pros and cons of the two approaches are compared, focusing on such issues as performance under conditions of uncertainty, volatility of the induced carbon prices, the excess burden of taxation and regulation, potential for corruption and accounting finagling, and ease of implementation. It concludes that, although virtually all discussions about economic global public goods have analyzed quantitative approaches, price-type approaches are likely to be more effective and more efficient.

I. The Status of the Current Kyoto Protocol [1]

After more than a decade of negotiations and planning under the Framework Convention on Climate Change (FCCC), the first binding international agreement to control the emissions of greenhouse gases has come into effect in the Kyoto Protocol. The first budget period of 2008-2012 is at hand. Moreover, the scientific evidence on greenhouse warming strengthens steadily as observational evidence of warming accumulates. The institutional framework of

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the Protocol has taken hold solidly in the EU's Emissions Trading Scheme (ETS), which covers almost half of Europe's CO_2 emissions.[2]

Notwithstanding this apparent success, the Kyoto Protocol is widely seen as somewhere between troubled and terminal. Early troubles appeared with the failure to include the major developing countries along with lack of an agreed-upon mechanism to include new countries and extend the agreement to new periods. The major blow came when the US withdrew from the Treaty in 2001. By 2002, the Protocol covered only 30 percent of global emissions, while the hard enforcement mechanism in the ETS accounts for about 8 percent of global emissions (see Figure 1). Even if the current Protocol is extended, models indicate that it will have little impact on global temperature change. Unless there is a dramatic breakthrough or a new design, the Protocol threatens to be seen as a monument to institutional overreach.

Nations are now beginning to consider the structure of climate-change policies for the period after 2008-2012. Some countries, states, cities, companies, and even universities are adopting their own climate-change policies. Is the current design a viable long-term approach to this long-term problem? Are there in fact alternatives to the scheme of tradable emissions permit embodied in the Protocol? The fact is that alterative approaches have not had a serious hearing among natural scientists or among policymakers. The only live alternatives considered for the control of greenhouse gases were standard command-and-control regulation or a variant in which permits are exchangeable. Most of the alternatives to the Kyoto Protocol adopted by states or considered by the U.S. government contain some mixture of emissions limits and technology standards. Are there alternatives?

II. Alternative Approaches to the Control of Global Public Goods

Climate change is a member of a special kind of economic activity known as *global public goods*. Global public goods are public goods whose influences are felt around the world rather than in one nation, town, or family. What makes global public goods different from other economic issues is that there are at best

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[2] The European Union web site provides an overview of the ETS at http://europa.eu.int/comm/environment/climat/emission.htm. For an economic analysis, see Gernot Klepper and Sonja Peterson, "Emissions Trading, CDM, JI, and More – The Climate Strategy of the EU," Kiel Working Paper 1238, February 2005.

weak economic and political mechanisms for resolving these issues efficiently and effectively.

It is customary to think of climate change as unique. In fact, dealing with global public goods has been an increasingly important feature of global affairs for centuries. Other important examples are national defense, public health, intellectual property rights, international trade, macroeconomic stability, fisheries, international environmental issues, endangered species, and transnational terrorism. We have only to think about nuclear proliferation, the AIDS epidemic, the threat of avian flu, the decline of many ocean fisheries, international financial crises, and the history of warfare to realize how prevalent are global public goods. A little further reflection will indicate that nations have had only modest success in combining to deal with global public goods. On the other hand, we can look to regimes to manage international trade disputes (today primarily through the World Trade Organization) or the chlorofluorocarbon protocols to indicate that all is not hopeless.

A review of mechanisms for dealing with global public goods reveals a wide variety of instruments or techniques.[3] A partial list is:

- Non-cooperative or laissez-faire approaches (as is currently taken for antibiotic resistance)

- Aspirational agreements (e.g., the FCCC) or non-binding voluntary agreements (e.g., the institutional regime created in the 1980s to clean up pollution in the North Sea)

- Specific and binding treaties – contracts between sovereign nations – which are the standard way to deal with international issues (currently in effect for the chlorofluorocarbons (CFCs) and many other global environmental agreements)

- Agreements embedded in broader arrangement (exemplified when Western nations forced developing countries to accept strong patent protection under the last multilateral trade negotiations)

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[3] A thorough study of international mechanisms for global public goods in the environment can be found in Scott Barrett, *Environment and Statecraft: The Strategy of Environmental Treaty-Making*, Oxford: Oxford University Press, 2003.

• Limited delegations of regulatory or fiscal authority to supranational bodies (seen in some European activities such as the European Central Bank, in some powers of the WTO, and the international financial institutions such as the IMF).

This array of international institutions reminds us that, although climate change is a new problem, the problems of international political economy raised by climate change are quite ancient.

There are two major problems involved in dealing with public goods. First, we must find the level of "appropriate federalism." That is, it is necessary to locate the decision making at the political level that can internalize the spillovers. This is a particularly thorny problem for global public goods because global inefficiencies intrinsically need global decision making, or at least global coordination. The second issue is the Westphalian dilemma. Under international law as it developed out of the 1648 Treaty of Westphalia and evolved in the West, obligations may be imposed on a sovereign state only with its consent. In other words, there is no legal mechanism by which disinterested majorities of countries can coerce free-riding countries into mechanisms that provide for global public goods.

These points are useful reminders that we must take entirely different approaches to global public goods from those taken to national public goods.

III. Mechanisms for Economic Public Goods

Looking at the varieties of global public goods, I want to focus on those that I will call *economic public goods*. These activities are ones involving huge numbers of economic agents in a large number of countries where the costs and benefits of action do not indicate any obvious focal policy or technological fix. The opposite of economic public goods is *focal public goods*, where good policies appear obvious or consensual to most people, such as no AIDS, no smallpox, no financial collapses, no nuclear meltdowns, no nuclear explosions, and no trade barriers.

With economic public goods, it is usually difficult to determine and reach agreement on efficient policies because they involve estimating and balancing costs and benefits, where neither is easy to measure and both involve major distributional concerns. Economic public goods include such examples as

fisheries (where most everyone agrees that some fishing is tolerable, but the point of overfishing is difficult to calculate); pollution (where most everyone agrees that zero pollution is prohibitively expensive); a multitude of societal risks (where it is difficult to decide where to set the safety margin between zero risk and "low" risk); and climate change (where almost everyone agrees that the optimal abatement is neither zero nor 100 percent of emissions). There is a temptation to redefine economic public goods as focal public goods because that tremendously simplifies analysis and policy. For example, policies have pretended to adopt a complete phase out of CFCs in principle, although that is impossible in practice. Policies to prevent the extinctions of species generally avoid the vexing question of how to draw the line between species and subspecies as well as the intractable question of how far to lower the probability of extinction given that it clearly can never be zero.

For economic public goods, there are three potential approaches: command-and-control regulation, quantity oriented market approaches, and tax or price-based regimes. Of these, only the tradable-quantity and the tax regimes have any hope of being reasonably efficient, and I will therefore limit my discussion to those cases.[4]

- *Quantitative limits.* Under a tradable quantity approach, an agreement proceeds by setting limits on emissions by different countries. The limits are partially or wholly transferable among countries. This is the approach taken under the Kyoto Protocol. This approach has very limited international experience under existing protocols such as the CFC mechanisms and somewhat broader experience under national trading regimes, such as the U.S. SO_2 regime.

- *Price or tax mechanisms.* A radically different approach is to use harmonized prices, fees, or taxes as a method of coordinating policies among countries. This approach has no international experience in the environmental area, although it has modest experience nationally in such areas as the U.S. tax on ozone-depleting chemicals. On the other hand, the

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[4] This list of two is obviously drastically simplified. For a nuanced discussion of many alternatives, see Joseph Aldy, Scott Barrett, and Robert Stavins, "Thirteen Plus One: A Comparison of Global Climate Policy Architectures," *Climate Policy,* vol. 3, no. 4, 2003, pp. 373-397 and the many references and proposals therein. These proposals include variants on the two basic control mechanisms plus a portfolio of other policies such as enhanced research and development.

use of harmonized price-type measures has extensive international experience in fiscal and trade policies, such as with the harmonization of taxes in the EU and harmonized tariffs in international trade.

IV. Major Issues in Any International Climate-Change Regime

Any climate-change regime must face three fundamental questions – the level of emissions reductions, the distributions of emissions reductions across countries, and the need for transfers to induce low-income countries to participate. Each of these issues is very contentious for climate change.

The overall level and trajectory of emissions reduction

Because climate change is a global public good, the key environmental question is global emissions, and the key economic issue is how much global emissions should be reduced. Climate change does not depend upon the exact location of greenhouse-gas emissions, but only upon the total and time path of emissions. Moreover, the impacts to a first approximation do not depend upon the annual flow of emissions but on concentrations, which are a complex function of cumulative emissions.

Under a quantitative approach, the level of emissions (in covered countries) is in principle directly chosen. Under a price approach, the level of emissions is indirectly determined by the level of the tax or penalty on carbon emissions. However, for a quantitative approach with trading, a market economy is likely to develop markets for emissions, and a market price will therefore emerge. An economist will naturally examine the price in either case, and the first question then will quickly be transformed into a slightly rephrased question: What is the level of the carbon price that is consistent with the regime?

In a world of certainty, either a quantitative or a price regime could target a given carbon price, but in practice the price is likely to be unknowable in advance in a pure quantitative system. The key economic question in either regime is whether the price is likely to be relatively high, say in the $100 per ton of carbon range, or relatively low, say in the $10 per ton carbon range.[5]

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[5] Scientists and economists have customarily quoted prices for carbon emissions in terms of carbon. Current emissions trading programs generally quote in terms of carbon dixodie, which has a mass 3.67 times that of carbon. To convert from the carbon

This issue has been at the heart of the debate about the efficiency of the Kyoto Protocol. Several economic studies have found that the Kyoto Protocol will not only lead to high carbon prices but also to a highly differentiated and therefore inefficient allocation of abatement across countries.[6] To the extent that an economic rationale lies behind the U.S. rejection of the Kyoto Protocol, it comes from estimates that the U.S. will bear a disproportionate share of the burden of adjustment and that the costs to the U.S. of the Kyoto Protocol far outweigh the benefits. Figure 2 presents an estimate of the economic impact (costs, benefits, and net benefits) of the full trading version of the *original* Kyoto Protocol using the RICE-2001 model.[7] These estimates indicate not only that the U.S. bears a large fraction of the costs of implementing the protocol but also that the net economic impact upon the U.S. is negative even including the environmental benefits. Figure 3 shows, by comparison, how the costs are radically altered by the U.S. withdrawal.

The question of the "right" or the "optimal" level of emissions reductions is undoubtedly the most difficult and controversial question in the economics of climate change. In a series of studies, my coauthors and I have estimated cost and damage functions and estimated "optimal" or cost-beneficial approach to climate change. Our latest estimates in the revised RICE-2001 model suggest that a 2010 carbon price of $16 per ton carbon (in 2005 prices) – rising rapidly over time – would appropriately balance the costs and benefits of emissions reductions using the classical cost-benefit approach. However, this estimate might not appropriately capture many non-market aspects of climate change and does not adequately capture many of the potential "dangerous interferences"

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units to the current convention of CO_2 units, multiply the mass, or divide the price, by 3.67.

[6] A standard reference on economic studies of the economic implications of the Kyoto Protocol is "The Costs of the Kyoto Protocol: a Multi-model Evaluation," *The Energy Journal*, special edition, May 1999. This was updated for the RICE model in William D. Nordhaus, "Global Warming Economics," *Science,* Vol. 294, N. 5545, Nov. 9, 2001, pp. 1283-1284.

[7] A description of the RICE model and the updates to 2001 is contained in the Appendix.

with many global processes.[8] Alternative estimates of carbon taxes would be ones that stabilize the concentrations of CO_2 at twice the pre-industrial level (that is, at 550 parts per million), which is estimated to be $8 per ton carbon in 2010; while an efficient trajectory for limiting temperature change to 2½ degrees Celsius would be $26 per ton carbon in 2010. The major conclusion from earlier studies is significant constraints on greenhouse-gas emissions would have price penalties on emissions in the range of $10 to $20 per ton of carbon in the 2010 time frame.

Modeling estimates indicate that global emissions under the revised Kyoto Protocol will be very close to "business as usual." Global emissions in 2010 under the current Protocol are estimated to be 1½ percent lower than a no-controls scenario if the new forestry offsets are ignored (see Figure 4) and around ¾ percent lower with forestry offsets (not shown).

Carbon prices in the implementing regions are projected to be sharply lower under the no-U.S. version compared to the original version. Model results indicate that the full-trade carbon price in 2010 would be $41 per ton carbon with the United States and $18 without the U.S. Actual market prices for the ETS have ranged from $23 to $104 per ton carbon. With the U.S. out of the picture, the price of permits in Europe falls dramatically as required emissions reductions decline. Figure 5 shows the estimated carbon prices in Europe for variants of the Kyoto Protocol as well as the actual price in the European Trading Scheme.

The distribution of emissions or emissions reductions among countries

Additionally, a global climate-change regime has important distributional dimensions: What should be the relative distribution of reductions among high- and low-income countries, among high-emitting and low-emitting countries, and among countries that are vulnerable to the consequences of climate change and those who are relatively less vulnerable?

The economic approach to these questions leads to a simple and unambiguous answer: emissions reductions should be done in the most efficient

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[8] The term is motivated by the Framework Convention, which states, "The ultimate objective of this Convention … is to achieve … stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

way; and the burden of reducing emissions should be shared in a fair way. The first half of this statement refers to the distribution of actual emissions reductions (which was just discussed) while the second half refers to burden sharing (which is discussed below).

Under the economic approach, emissions reductions will be efficient if the marginal costs of emissions reductions are equalized with appropriate discounting across space and time. The spatial component of efficiency is that the marginal cost of reductions should be equal across all countries and industries. The temporal component is more complicated.

A more complex requirement is "when efficiency" or intertemporal efficiency. To a first approximation, intertemporal efficiency requires that the price or marginal cost of emissions reductions grows over time at a rate equal to the "real carbon interest rate," which is approximately equal to the real interest rate less the disappearance rate of CO_2 from the atmosphere. Most analyses focus only on the spatial component, which is always necessary for efficiency, and ignore the temporal component because it requires a complicated intertemporal optimization.

The Kyoto Protocol is defective on both efficiency criteria because it omits a substantial fraction of emissions (thus failing the spatial criterion) and has no plans beyond the first period (thus failing the temporal dimension). Indeed, the two largest emitters (the U.S. and China) are not even included in the current protocol, and a third (Russia) has agreed to join only because it is the recipient of large transfers. Figure 6 shows the most recent estimates of the abatement costs under different trading regimes for the original Kyoto Protocol using the RICE-2001 model.[9] Because it limits trading to a small part of the world and ignores the intertemporal dimension, the Kyoto Protocol is an extremely costly treaty and makes only modest progress in slowing global warming.

Income transfers from high-income to low-income countries

All studies show that it is efficient for low-income counties to participate in emissions reductions, and indeed some of the most economical emissions

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[9] These show the discounted costs of abatement using a real discount rate that begins at about 5 percent per year today and falls to around 3½ percent per year in a century.

reductions will probably come in low-income countries. In both quantity-type and price-type mechanisms, it will be both necessary and fair for high-income countries to provide assistance to low-income countries if the latter are to be expected to take measure to reduce emissions. The transfer mechanism under a quantity approach takes place through the allocation of baseline emissions. Under a fiscal mechanism, transfers would be direct monetary transfers or transfers tied to projects and would therefore be much more visible. Whatever the mechanism, some form of transfer will be necessary.

This set of concerns has been another obstacle to ratification of the Kyoto Protocol in the United States. Both the FCCC and the Kyoto Protocol exempt the developing countries, even relatively affluent ones, from obligations for emissions reductions. It is obviously crucial to have a mechanism whereby countries "graduate" into a set of obligations that are commensurate with their abilities to pay – in a way that is similar to the ability to pay principles of an income tax system.

The Kyoto Protocol has an arbitrary allocation of transfers because it generally used 1990 emissions as a base year when setting targets in 1997. Consequently, those countries with high emissions in 1990 (such as the former Soviet Union) will be advantaged while those who have grown rapidly (such as the United States) will be disadvantaged. Moreover, since developing countries are omitted, they are completely overlooked in the transfers. Although there have been few public pronouncements on the subject, it is inconceivable that the United States would agree to the enormous resource transfers to Russia and other countries that are envisioned by the Kyoto Protocol.[10] Therefore, while the quantity plan looks advantageous because it contains implicit transfers, when the time comes actually to purchase substantial emissions reductions from Russia, the political glue might well come unstuck.

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[10] Estimates of transfers vary considerably across models. For example, in the RICE-2001 model, transfers from high-income countries (principally the U.S.) to Russia and other eastern European countries are estimated to be around $40 billion per year in 1990 prices.

V. Sketch of a Price-Type Approach to Climate Change

Price-type approaches have been discussed in a handful of papers in the economics literature,[11] but much careful analysis remains to be done. I will highlight a few of the details.

For concreteness, I will discuss harmonized carbon taxes (HCT). Under HTC, there are no international or national emissions limits; rather, countries would agree to penalize carbon emissions domestically at an agreed-upon and harmonized "carbon tax." Conceptually, the carbon tax is a dynamically efficient Pigovian tax that balances the discounted social marginal costs and marginal benefits of additional emissions. In practice, the tax might be set by aiming to limit GHG concentrations or to keep temperature changes below some level, or it might use some kind of cost-benefit approach.[12] Unlike the quantitative approach under the Kyoto Protocol, there are no country emissions quotas, there is no emissions trading, and there are no base period emissions levels. Because carbon prices will be equalized, the approach will be spatially efficient among those countries that have a harmonized set of taxes. If the carbon tax trajectory follows the rules for "when efficiency," it would also satisfy intertemporal efficiency. Studies of efficient prices find that the real carbon prices would rise by between 2 and 4 percent per year depending upon the objective.

Details about burden sharing would require study and negotiations. It would be reasonable to allow participation to depend upon the level of economic development. For example, countries might be expected to participate fully when their incomes reach a given threshold (perhaps $10,000 per capita), and poor countries might receive transfers for early participation. The issues of sanctions, the location of taxation, international-trade treatment, and transfers to

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[11] There are few serious discussions of the structure of a regime based on price-type instruments. Some examples are Richard Cooper, "Toward a Real Treaty on Global Warming, *Foreign Affairs*, vol. 77, no. 2, 1998, pp. 66-79; William A. Pizer, "Prices vs. Quantities Revisited: The Case of Climate Change," Resources for the Future Discussion Paper 98-02 (revised), December 1998; David Victor, *The Collapse of the Kyoto Protocol and the Struggle to Slow Global Warming,* Princeton University Press, Princeton, NJ, 2001. Also see the general comparison in the paper by Aldy, Barrett, and Stavins, *op. cit.*

[12] There are many studies linking carbon taxes to different objectives. For example, Nordhaus and Boyer, *Warming the World, op. cit.* examine the carbon taxes associated with temperature, concentrations, and emissions limits as well as those that maximize net economic benefits.

developing countries under an HCT are important details that are subject to discussion and refinement.[13] If carbon prices are equalized across participating countries, there will be no need for tariffs or border tax adjustments among participants. I emphasize that much work would need to be done to flesh out these arrangements, but they are familiar terrain because countries have been dealing with problems of tariffs, subsidies, and differential tax treatment for many years.

Hybrid approaches

The literature on regulatory mechanisms entertains a much richer set of approaches than the polar quantity and price types that are examined here. An important variant is "prices in quantity clothes" – putting price ceilings and floors on the price emissions-trading permits.[14] This was considered and rejected by the Clinton Administration in its preparation for the negotiations for the Kyoto Protocol.

The present discussion focuses on pure strains of the two systems partially to keep the analysis within manageable limits. Additionally, we may worry about the tendency of mixed systems to revert to their archetype. For example, even though the Kyoto Protocol was designed as a system with complete trading within the Annex I countries, there were strong pressures to limit trading and force countries to make much of their reductions internally. The EU implementation of the Kyoto Protocol allows full trading within the EU but limits the purchases of emissions permits from other countries. The lesson from foreign-trade barriers, where price and quantity limits have a much longer history, is that the quantity limits through quotas are extremely durable.

VI. Comparison of Price and Quantity Approaches

Quantity approaches are the norm in environmental policies today, and policies toward global warming are no exception. Policymakers, environmentalists, and economists are so accustomed to quantity constraints in

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[13] Many of these have been carefully analyzed in the context of the ETS. There is an important advantage for these purposes of uniform pricing, as will be discussed below.

[14] Warwick J. McKibbin and Peter Wilcoxen, "A Better Way to Slow Global Climate Change," Brookings Policy Brief No. 17, Washington, D.C., 1997.

environmental policy that the fundamental advantages of price-type approaches have been largely overlooked. This section reviews ten differences between quantity and price approaches with an emphasis on the advantages of the price-type mechanisms for climate-change policies.

1. The fundamental defect of the Kyoto Protocol is that the policy lacks any connection to ultimate economic or environmental policy objectives. The approach of freezing emissions at a given historical level for a group of countries is not related to any identifiable goals for concentrations, temperature, costs, damages, or "dangerous interferences." Nor does it bear any relation to an economically oriented strategy that would balance the costs and benefits of greenhouse-gas reductions. It is not inevitable that quantity-type arrangements are inefficient. In principle, they might be designed to choose an emissions path that meets some well-defined and well-designed economic and environmental objectives. However, in practice, quantity approaches in environmental policy tend to be technologically oriented.

Price-type systems such as taxes have a mixed record of efficiency. In this context, the ideal system is relatively simple, as has been described in the section on harmonized carbon taxes above, and is simply the dynamically efficient Pigovian tax. Because of its conceptual simplicity, it might prove simpler to target an efficient tax in this area than efficient quantities.

2. A related issue concerns the baseline policy against which countries set their policies. Quantity limits are particularly troublesome in a world of growing economies, differential economic growth, and uncertain technological change. These problems have become evident under the Kyoto Protocol, which set its targets thirteen years before the control period and used baseline emissions from *twenty years* before the control period. Base year emissions have become increasingly obsolete as the economic and political fortunes of different countries have changed. The 1990 base year penalizes efficient countries (like Sweden) or rapidly growing countries (such as Korea and the United States). It also gives a premium to countries with slow growth or with historically high carbon-energy use (such as Britain, Russia, and Ukraine).

The baselines for future budget periods and for new participants are further profound problems for the Kyoto Protocol. The natural baseline, were it feasible to calculate, is the zero-restraint level of emissions. That level is in practice impossible to calculate or predict with accuracy, particularly when

abatement policies are in place. Problems would arise in the future as to how to adjust baselines for changing conditions and to take into account the extent of past emissions reductions.

Under a price approach, the natural baseline is a zero-carbon-tax level of emissions, which is a straightforward calculation for old and new countries (more on this below). Countries' efforts are then judged relative to that baseline. It is not necessary to construct a historical base year of emissions. Countries are not advantaged or disadvantaged by their past policies or the choice of arbitrary dates. Moreover, there is no asymmetry between early joiners and late joiners.[15]

3. One key difference between price and quantity instruments concerns the structure of the uncertainties — and uncertainty is clearly a central feature of climate-change policy. As is well-known in the static Weitzman problem, if the curvature of the benefit function is small relative to the curvature of the cost function, then price-type regulation is more efficient; conversely, if the benefit functions are highly nonlinear while the cost functions are close to linear, then quantity-type regulation is more efficient.

While this issue has received little attention in the design of climate-change policies, the structure of the costs and damages in climate change gives a strong presumption to price-type approaches.[16] The reason is that the benefits are related to the stock of greenhouse gases, while the costs are related to the flow of emissions. This implies that the marginal costs of emissions reductions are highly sensitive to the level of reductions, while the marginal benefits of emissions reductions are essentially invariant to the current level of emissions reductions. More generally, where the damages are caused by stock externalities (as is the case for climate change because damages are a complicated function of the stock of greenhouse gases), then the damage function is likely to be close to linear with

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[15] Under the Kyoto Protocol, Annex I countries have a fixed 1990 base, while late joiners have no base or, implicitly under article 12, a base emissions trajectory which is their uncontrolled emissions.

[16] This point has been discussed by William Pizer, "Optimal Choice of Climate Change Policy in the Presence of Uncertainty," *Resource and Energy Economics,* 1999, vol. 21, no. 3-4, pp. 255-287 and Michael Hoel and Larry Karp, "Taxes and Quotas for a Stock Pollutant with Multiplicative Uncertainty," *Journal of Public Economics,* 2001, vol. 82, pp. 91-114. The latter study applies the theory to global warming and finds that for a stylized model taxes dominate quotas by a large margin.

respect to current emissions. Abatement costs, by contrast, are likely to be highly nonlinear as a function of emissions. This combination of nonlinearities means that emissions fees or taxes are likely to be much more efficient than quantitative standards or auctionable quotas when there is considerable uncertainty, as is clearly the case for climate change.

4. Closely related to point about uncertainty is that quantity-type regulations are likely to show extremely volatile prices for the trading prices of carbon emissions. Carbon prices are likely to be extremely volatile because of the complete inelasticity of supply of permits in the quantity case along with the presumption of quite inelastic demand for permits in the short run.[17]

We have preliminary indications that European trading prices for CO_2 are highly volatile, fluctuating in a band and $\pm$ 50 percent over the last year. More extensive evidence comes from the history of the U.S. sulfur-emissions trading program. SO_2 trading prices have varied from a low of $70 per ton in 1996 to $1500 per ton in late 2005. SO_2 allowances have a monthly volatility of 10 percent and an annual volatility of 43 percent over the last decade. Figure 7 shows that sulfur prices are much more volatile than oil prices or stock-market prices. This is analogous to a carbon-trading program because the supply is virtually fixed and the demand is inelastic because of the low substitutability of other inputs for sulfur in the short run. Both programs build in some banking features, which can in principle moderate price volatility.

Such rapid fluctuations would be extremely undesirable, particularly for an input (carbon) whose aggregate costs might be as great as petroleum in the coming decades. An analogous situation occurred in the U.S. during the "monetarist" period of 1979-82, when the Federal Reserve targeted quantities

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[17] To some extent, the volatility can be moderated by banking and borrowing. However, borrowing and banking require durable long-term agreements about allocations, which are much more difficult to impose under international law than under most national legal systems because most treaties allow countries to withdraw and there is no supranational mechanism for enforcing property rights. It is highly unlikely that any program would allow borrowing. Moreover, note that there is substantial banking allowed under the U.S. SO_2 program. Issues of pricing of bankable permits is analyzed in Matti Liski and Juan-Pablo Montero, "Market power in a storable-good market: Theory and applications to carbon and sulfur trading," Working Paper, November 18, 2005.

(monetary aggregates) rather than prices (interest rates). During that period, interest rates were extremely volatile. In part due to the increased volatility, the Fed changed back to a price-type approach after a short period of experimentation. This experience suggests that a regime of strict quantity limits might become extremely unpopular with market participants and economic policymakers if carbon price variability caused significant changes in inflation rates, energy prices, and import and export values.

5. A fourth advantage of tax mechanisms is the strong fiscal-policy preference for using revenue-raising measures rather than quantitative or regulatory measures. When prices are raised and real incomes are reduced by regulations, this increases the inefficiency losses from the overall tax system. This effect is the "double burden" of taxation (misnamed as the "double dividend" from green taxes).[18] If the carbon constraints are imposed through taxes that are then rebated in taxes with approximately the same marginal deadweight loss as the carbon taxes, then the overall efficiency loss from taxation will be unchanged. If the constraints under a quantity-based system are imposed by allocations that do not raise revenues, then the conventionally calculated abatement costs will underestimate the economic costs and the efficiency losses from the price-raising elements should be added to the abatement costs. The impacts are likely to be large.[19]

While it is possible that emissions permits will be auctioned (thereby retaining the revenues and removing the double burden of taxation), history and

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[18] See Lawrence Goulder, Ian Parry, and Dallas Burtraw, "Revenue-Raising vs. Other Approaches to Environmental Protection: The Critical Significance of Pre-Existing Tax Distortions," *RAND Journal of Economics*, Winter 1997, pp. 708-731 and Lawrence Goulder and A. Lans Bovenberg, "Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analyses," *American Economic Review*, September 1996, pp. 985-1000.

[19] There are no well-accepted estimates of the efficiency losses from allocation as compared to taxes or auctioning emissions permits, but we can get an order of magnitude estimate. Using the United States in 2010 as an example, GDP in 2010 is about $15,000 billion (in 2005 dollars). Assume that an emissions tax of $100 per ton led to an emissions level of 1.5 billion tons of carbon. Then with a marginal deadweight loss per dollar of revenue loss of 0.4, the additional loss would be $60 billion per year on top of the abatement costs of about $15 billion for that year. There are clearly big stakes here.

current proposals suggest that most or all of the permits are likely to be allocated at zero cost to "deserving" parties, or will be distributed to reduce political frictions. In the cases of SO_2 allowances and CFC production allowances, *all* the permits were allocated to producers. The point here is that using tax approaches rather than quantity-type approaches will help promote a more efficient collection and recycling of the revenues from the carbon constraints.

6. An additional question applies particularly to international environmental agreements and concerns the administration of programs in a world of where governments vary in terms of honesty, transparency, and effective administration. One of the subtle and overlooked problems with quantity-type systems is that they are much more susceptible to corruption than price-type regimes. An emissions-trading system creates valuable tradable assets in the form of tradable emissions permits and allocates these to different countries. Limiting emissions creates a scarcity where none previously existed – in essence printing money for those in control of the permits. Such wealth creation is potentially dangerous because the value of the permits can be used by the country's leaders for non-environmental purposes rather than to reduce emissions. It would probably become common practice for dictators and corrupt administrators to sell part of their permits, pocket the proceeds, and enjoy wine, partners, and song along the Riviera. Some analysts even believe that the presence of rents of this kind is harmful to economic growth (the "resource curse").[20]

A few examples will show the perils in the quantitative approach. Simulations suggest that tens of billions of dollars of permits may be available for export from Russia under the Kyoto Protocol. A Russian scientist recently reported that people in Moscow were already considering how to profit from the "privatization" of the Russian carbon emissions permits. Alternatively, consider the case of Nigeria, which had emissions of around 90 million tons of CO_2 emissions in recent years. If Nigeria could sell its allowances for $20 per ton under a "clean development mechanism," this would raise around $2 billion each year of hard currency. This is in a country whose non-oil exports in 2000 were around $600 million.

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[20] Ragnar Torvik, Natural Resources, Rent Seeking and Welfare, *Journal of Development Economics*, 2002, vol. 67, pp. 455-470.

To prevent unacceptable diversions of funds, any broad-based emissions-trading plan would undoubtedly lead to a major monitoring system and might get bogged down in concerns about the diversion of funds to arms purchases, drugs, money laundering, and terrorism. It would be tempting to make participation and receipt of permits conditional on "good behavior" with respect to terrorism, human rights, environmental concerns, child and prison labor, and other worthy causes du jour. Reducing emissions permits would be a tempting target for sanctions for countries who violate international norms. Of course, the more burdensome are the "ethical" restrictions on the sale of the permits, the less attractive participation becomes for countries, so the plan could easily founder.

A price approach gives less room for corruption because it does not create artificial scarcities, monopolies, or rents. There are no permits transferred to countries or leaders of countries, so they cannot be sold abroad for wine or guns. Any revenues would need to be raised by taxation on domestic consumption of fuels. In fact, a carbon tax would add absolutely nothing to the instruments that countries have today. The only difference would be the international approval of carbon taxes, which probably adds little to their acceptability in corrupt or weakly governed countries. The dangers of quantity as compared to price approaches have been shown frequently when quotas are compared to tariffs in international trade interventions.

7. Problems of financial finagling are not limited to poor, weak, and autocratic states. Concerns arise in the wake of the recent accounting scandals in the U.S. A cap-and-trade system relies upon accurate measurement of emissions by all relevant parties. If firm A (or country A) sells emissions permits to firm B (or country B), where both A and B are operating under emissions caps, then it is essential to monitor the emissions of A and B to make sure that their emissions are in fact within their specified limits. Indeed, if monitoring is ineffective in country A but effective in country B, a trading program could actually end up raising the level of global emissions because A's emissions would be unchanged while B's would rise.

It was generally supposed that monitoring would be relatively straightforward in countries with strong legal and enforcement systems such as the United States. This was probably naïve and overly optimistic. The accounting scandals of the last decade have not been limited to dollar scandals, but these have also spilled over into emissions markets.

Some recent cases were described by Ruth Greenspan Bell:[21]

> PSEG Fossil LLC, the biggest player in [New Jersey's emissions trading system], apparently had not installed necessary pollution controls or obtained proper permits. The U.S. Justice Department discovered this and brought an enforcement action, which was resolved in the form of a consent decree. PSEG, without admitting any wrongdoing, agreed to stop selling its credits to other firms and to stay out of the trading system. When PSEG was forced to withdraw, its sheer size and status as one of the largest "suppliers" of credits in New Jersey brought that state's system close to collapse.

> [A]ccording to ... Electricity Daily, [authorities] are looking into charges that a Pasadena broker cheated several firms who paid for emissions credits that were never delivered.... A similar example from the United Kingdom was reported ... in an account of a government-sponsored auction in which participating companies bid by offering greenhouse gas reductions. An independent review by Environmental Data Services noted strong grounds to suspect that at least half of the claimed emissions reductions were not real, and blamed the inaccuracies on shortcomings in the Department of Environment, Food, and Rural Affairs regulatory controls and "poorly thought through rules."

If emissions finagling takes place in countries with relatively solid legal systems like the United States and the United Kingdom, it would be foolish to overlook the likelihood of emissions cheating in Russia, Ukraine, and many developing countries.

Such cheating will probably be pandemic in an emissions-trading system that involves large sums of money. There are very poor intrinsic incentives for honesty in a cap-and-trade system. The purchasing unit gets a permit whether or not any true reductions take place by the selling unit. Emissions evasion has even worse incentives than tax evasion. Unlike the emissions-permit case, the recipient of the tax wants the payer to dispense the funds just as much as the taxpayer dislikes dispensing the funds. Tax cheating is a zero-sum game for the two parties, while emissions evasion is a positive sum game for the two parties. If tax evasion in the U.S. is in the order of 10 or 20 percent of taxes due, is there reason to believe that emissions evasion in Ukraine or Romania would be substantially less?

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[21] "Climate Change Monitoring: International Greenhouse Gas Emissions Trading," http://www.emissierechten.nl/climate_change__monitoring_inter.htm .

8. One objection to the carbon-tax approach concerns its administration. The issue has been analyzed by David Victor in his analysis of the Kyoto Protocol:

> Monitoring and enforcement [of a carbon tax approach] are extremely difficult. . . . In practice, it would be extremely difficult to estimate the practical effect of the tax, which is what matters. For example, countries could offset a tax on emissions with less visible compensatory policies that offer loopholes for energy-intensive and export-oriented firms that would be most adversely affected by the new carbon tax. The resulting goulash of prior distortions, new taxes, and political patches could harm the economy and also undermine the goal of making countries internalize the full cost of their greenhouse gas emissions.[22]

I believe such concerns are serious but can be overcome. The major obstacle to enforcement is the measurement of "net carbon taxes." As Victor notes, we would need to measure net carbon taxes in the context of other fiscal policies (such as fuel taxes and coal subsidies). For example, suppose that Germany imposed a $50 carbon tax, which would fall primarily on coal. It might at the same time increase its coal subsidies or reduce its gasoline taxes to offset the carbon tax, thereby reducing the level of net carbon taxes. Alternatively, Canada might argue that it has met its carbon-tax obligations by raising provincial stumpage charges on timber. How would the carbon tax be calculated in such circumstances?

One approach would be to calculate that net taxation of carbon fuels including all taxes and subsidies on energy products but not going to second-level tax impacts except in exceptional cases. Such a calculation would require two steps. First, each country would provide a full set of taxes and subsidies relating to the energy sector; second, we would need an appropriate methodology for combining the different numbers into an overall carbon tax rate.

The first issue – obtaining tax rates – is relatively straightforward for market economies. One of the proponents of the tax approach, Richard Cooper, describes the monitoring issue as follows:

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[22] David Victor, *The Collapse of the Kyoto Protocol, op. cit.*, p. 86.

Monitoring the imposition of a common carbon tax would be easy. The tax's enforcement would be more difficult to monitor, but all important countries except Cuba and North Korea hold annual consultations with the International Monetary Fund on their macroeconomic policies, including the overall level and composition of their tax revenues. The IMF could provide reports to the monitoring agent of the treaty governing greenhouse gas emissions. Such reports could be supplemented by international inspection both of the major taxpayers, such as electric utilities, and the tax agencies of participating countries.[23]

Additionally, the levels of taxes and subsidies are generally public knowledge, particularly in market democracies, where they are part of the legislative process. On the other hand, countries with closed political systems might attempt to hide their subsidies. This problem would be particularly troublesome in non-market economies or sectors where fuels are allocated by quantitative measures rather than by the price mechanism. Direct allocation is becoming the exception rather than the rule.

The second issue, calculating the effective carbon tax from the underlying data, is essentially a technical economic issue. Calculations would require certain conventions about how to convert energy taxes into their carbon equivalent. Some of the calculations involve conversion ratios (from coal or oil to carbon equivalent) that underpin any carbon-based system, whether price-based or quantity-based. Others would require input-output coefficients, which might not be universally available on a timely basis. On the whole, calculations of effective carbon tax rates are straightforward as long as they involve first-round or impact calculations (i.e., the rate of tax per unit of carbon emitted) and do not need to involve substitution effects.

To go beyond first-round calculations would require assumptions about supply and demand elasticities and cross-elasticities, might engender disputes among countries, and should be avoided if possible. The procedures would probably require mechanisms similar to those used in WTO deliberations, where technical experts would calculate effective taxes under a set of guidelines that would evolve under quasi-legal procedures.[24] Overall, measurement and calculation of effective carbon tax rates seems more tedious than insuperable.

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[23] Cooper, *op. cit.*

[24] There is a substantial body of work on "ecological" and "green" taxes. Some of the literature is accessible at www.globalpolicy.org/socecon/glotax/biblio/index.htm .

9. An important issue involves the question of how to count initial carbon taxes. Some countries — particularly those in Europe — might claim that they already have high carbon-equivalent taxes because of high taxes on gasoline. They would argue for taking existing taxes into account before requiring them to undergo further obligations.

While this looks like a subterfuge, counting pre-existing taxes as compliance is appropriate and is easily seen as such in the carbon-tax framework. From the point of view of global efficiency, it makes no sense for countries with high existing taxes to add further penalties on top of existing ones before countries with subsidies or no penalties impose their carbon taxes. Therefore, the first step, and one absent from analysis of the Kyoto Protocol, would be a calculation of existing equivalent carbon taxes and subsidies. Our data suggest that, even without its CO_2 taxes, Europe is taxing carbon at a rate of approximately $100 per ton carbon more than the United States.[25] Given that disparity, it would make no economic sense to require Europe to add even higher carbon taxes on top of its existing ones before other countries had raised their carbon taxes. Moreover, the fact that Europe might be overtaxing carbon today would never come up in the quantity-type approach.

10. The fundamental intuitive concern about price-type approaches is that they fail to "solve" the climate-change problem because they do not limit emissions. This objection is wrong because there is no "correct" level of emissions or of emissions reductions. Indeed, there is today no agreed-upon upper limit on concentrations or temperature change. The price approach reflects the view that we have a better estimate of the size of the penalty on carbon emissions that should be imposed over the next one or two decades than we do of the level of allowable emissions over that period.

Putting this differently, emissions limitation is only an intermediate objective. It is preferable to steer policy toward the ultimate objectives of reducing concentration or temperature changes or limiting net environmental damages rather than at intermediate and intrinsically unimportant objectives like emissions. And this point is emphatically reinforced by the large uncertainties and evolving scientific knowledge. A control mechanism should allow iterative

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[25] See William Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming*, MIT Press, 2000, and the associated data sheets.

adjustment and movement toward evolving goals, which can be accomplished using either prices or quantities. However, while either prices or quantities can be used as a control mechanism, emissions taxes are more efficient in the face of massive uncertainty because of the relative linearity of the benefits with respect to emissions and the resulting high volatility of prices under an emissions-targeting approach. In other cases, quantities would be more appropriate, but in the case at hand – with a stock externality and vast uncertainty – using quantity controls gives a false impression that the problem is under control.

Non-economists will probably always be uncomfortable with using indirect instruments like prices, just as patients may wonder how little yellow pills can cure their disease. Nonetheless, the fact that prices are more indirect than quantity restraints should not prevent us from recognizing their superior power as a coordinator and motivator for global warming.

VII. Conclusion

All evidence suggests that we are just beginning to understand and cope with the "great geophysical experiment" of global warming. Nations must work together to protect the global environment just as much as to prevent tyranny, disease, poverty, and war.

The coming years will undoubtedly witness intensive negotiations on global warming as concerns mount and the quantitative approach under the Kyoto Protocol proves ineffective and inefficient. As policy makers search for more effective and efficient ways to slow the trends, they should consider the fact that price-type approaches like harmonized environmental taxes on carbon are powerful tools for coordinating policies and slowing climate change.
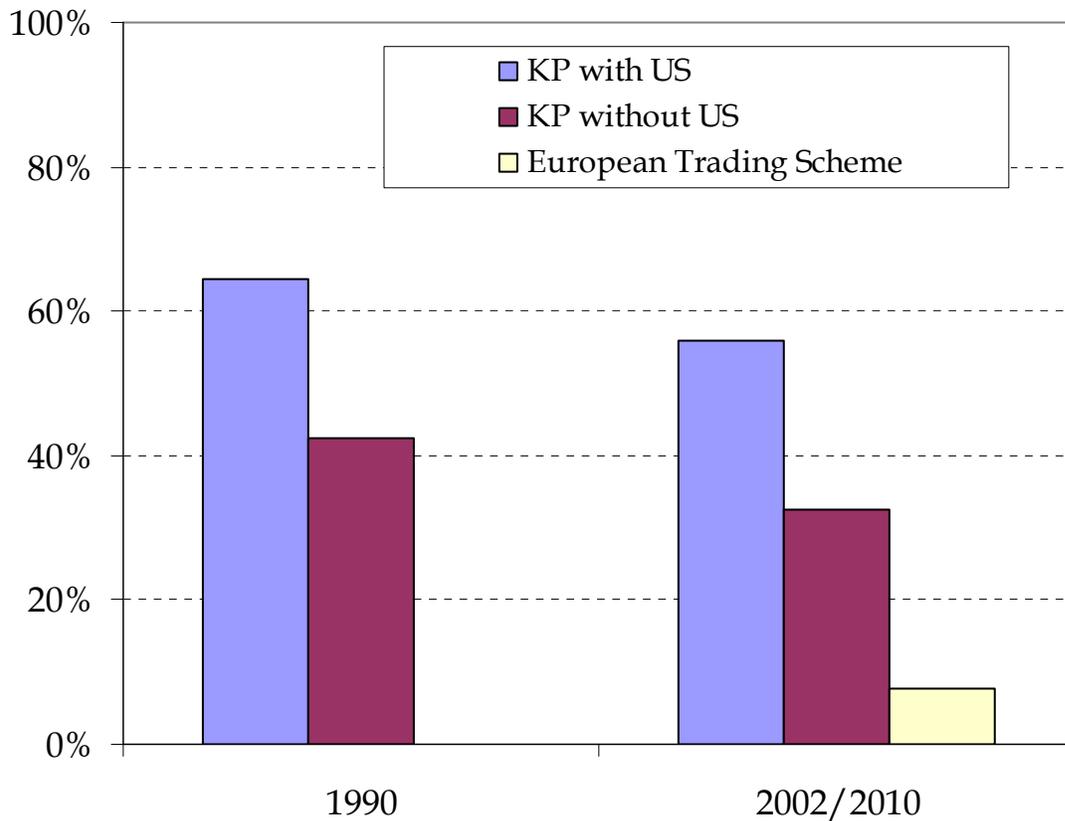
Figure 1. Fraction of world emissions covered by Kyoto Protocol

This figure shows that the coverage of the Kyoto Protocol has undergone serious attrition with the withdrawal of the United States and the growing importance of developing countries. The hard restrictions of the European Trading Scheme will cover only about 8 percent of global emissions in 2010. The data "2002/2010" should be interpreted as the date 2002 applying to the Kyoto Protocol coverage and the 2010 applying to the application of the ETS.

Net Impact of Kyoto Protocol: Full Trading
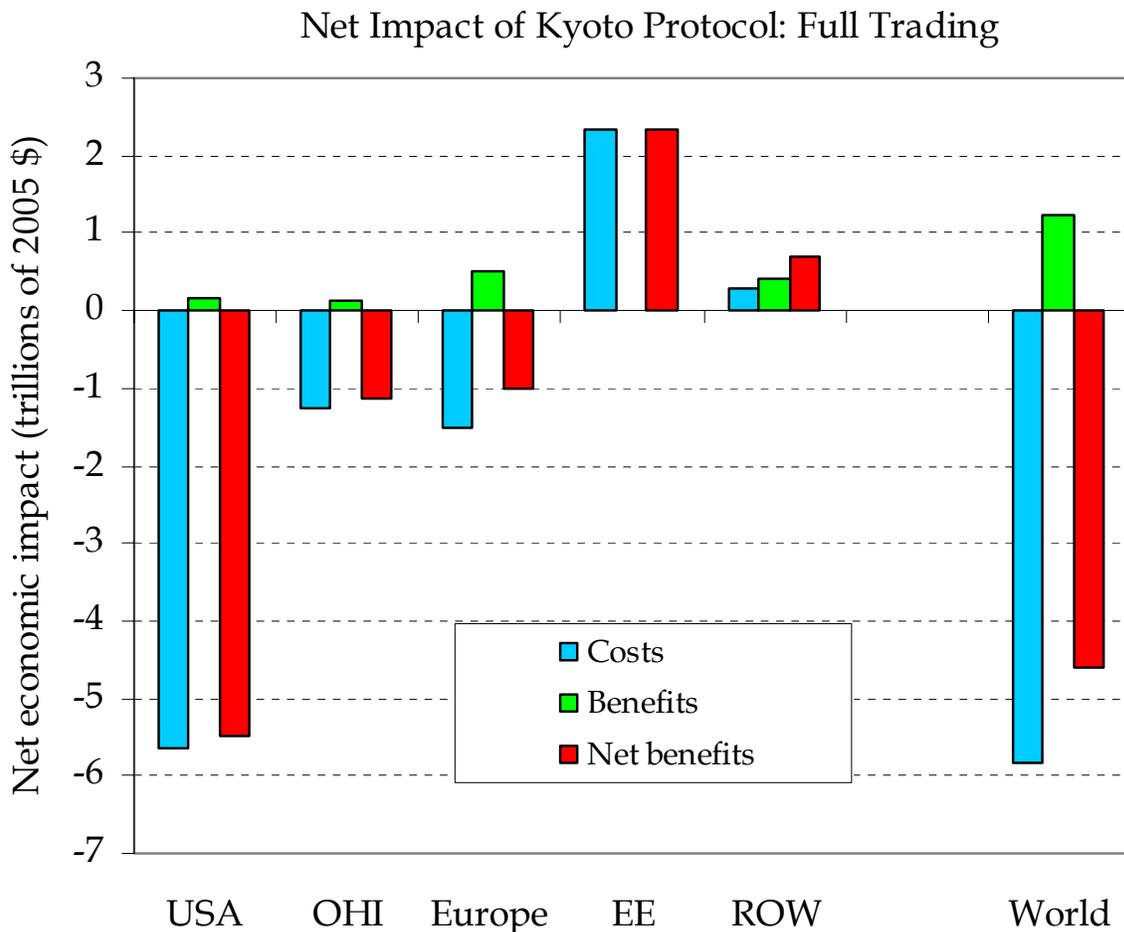
Figure 2. Costs and Benefits of the Original Kyoto Protocol

Figure shows the estimated costs and benefits of the original Kyoto Protocol estimated in the RICE-2001 model for different regions. The figure shows the costs and benefits of the Kyoto Protocol (with full Annex I trading) for the major regions. *Costs* are production costs (measured negatively), *benefits* are the environmental benefits of reduced climate change, and *net benefits* are the difference between costs and benefits. All figures are relative to the no-control baseline. Estimates are converted to 2005 using the ratio of world PPP GDP in 2005 to estimated world GDP in 1990.

Source: The underlying model is described in William Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming*, MIT Press, 2000, Chapter 8. Input data are revised to reflect changes in trends since 1999.

Note on regions:
"OHI" is other high-income countries, including Japan and Canada.
"Europe" is primarily the European Union
"EE" is Eastern Europe and the countries of the former Soviet Union
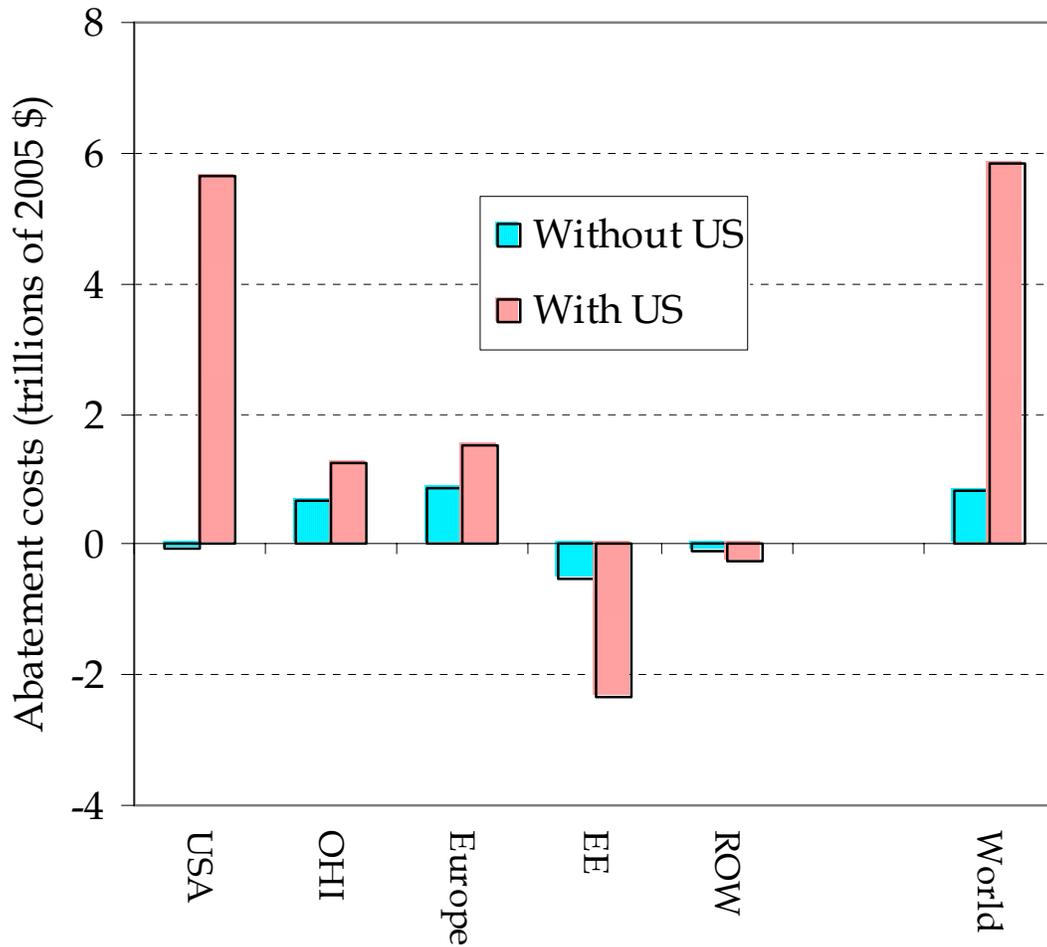"ROW" is the rest of the world

Figure 3. Abatement Costs of Kyoto Protocol without United States Participation

The burden of abatement shifts greatly with the U.S. withdrawal from the Kyoto Protocol. Note that costs are measured negatively, as in Figure 1.
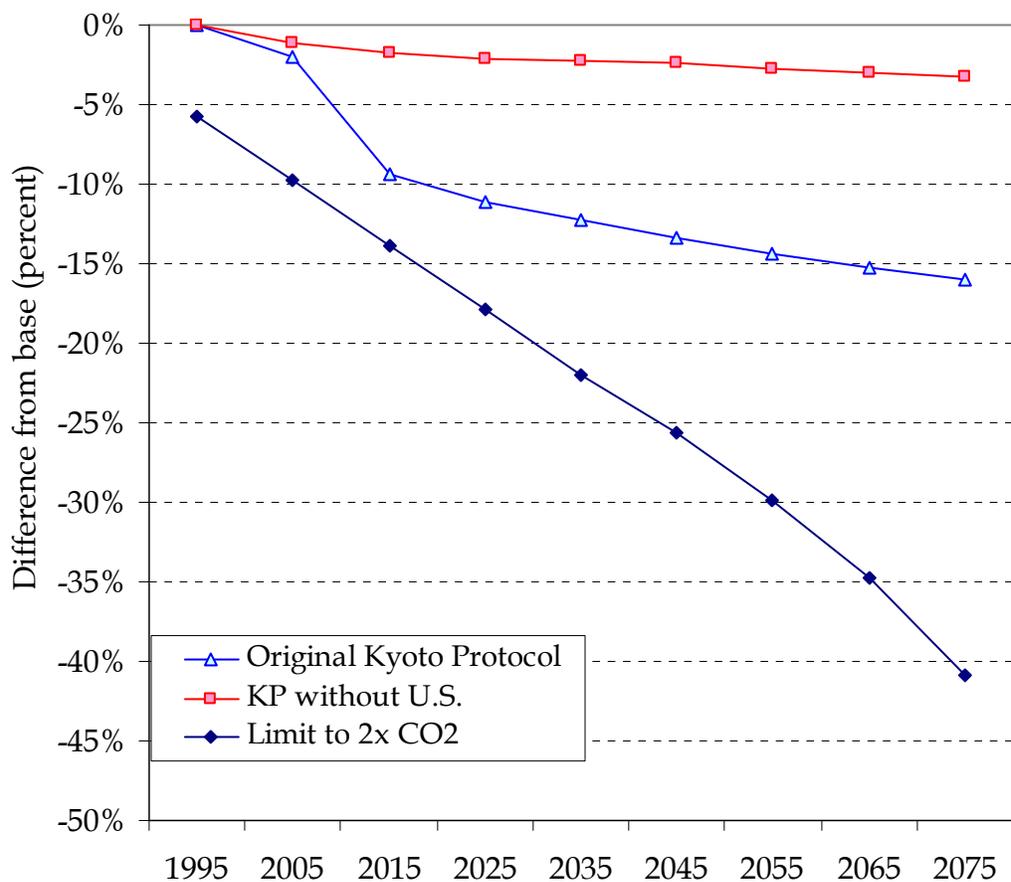
Source: See Figure 2.

Figure 4. Estimated Emissions Reductions Under Different Scenarios.

Numbers are for total global industrial CO_2 emissions and measure the percent reduction relative to a "business as usual" path of no emissions reductions (or zero carbon prices). The "Original Kyoto Protocol" shows the impact of the Protocol with U.S. participation. "Kyoto Protocol without U.S." shows the impact of removing the U.S. from the Protocol. The "Limit to 2xCO2" shows the emissions reductions that would minimize the costs of limiting CO_2 concentrations to double pre-industrial concentrations (i.e., to 550 ppm). The estimates are for the decades centered on the listed year. Estimates do not include reductions in targets due to new provisions regarding sinks and other technicalities contained in the most recent version of the Kyoto Protocol.
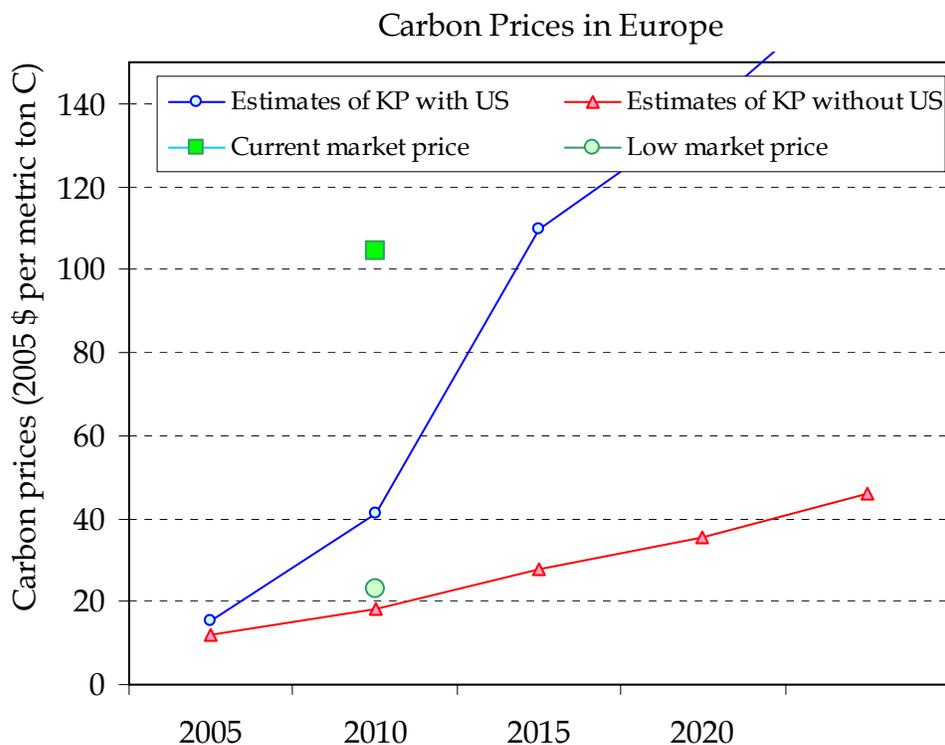
Source: See Figure 2.

Carbon Prices in Europe

Figure 5. Carbon prices in Europe and Other Countries Implementing the Kyoto Protocol

The estimates with and without the Kyoto Protocol (KP) are as described above from the revised RICE-2001 model. The estimates of the current market price are from the European Trading Scheme as reported in http://www.pointcarbon.com/. The estimates are for the decades centered on the listed year.

Note: Emission-permit prices are zero in developing countries under both versions of the Kyoto Protocol, and are zero in the U.S. when it does not participate. Model estimates of carbon prices are the estimated market price of permits to emit carbon dioxide measures in 2005 U.S. dollars per ton carbon. These results assume full trading. Note that the actual prices outside the ETS are highly divergent across sectors and countries (see Gernot Klepper and Sonja Peterson, "Emissions Trading, CDM, JI, and More – The Climate Strategy of the EU," Kiel Working Paper 1238, February 2005).
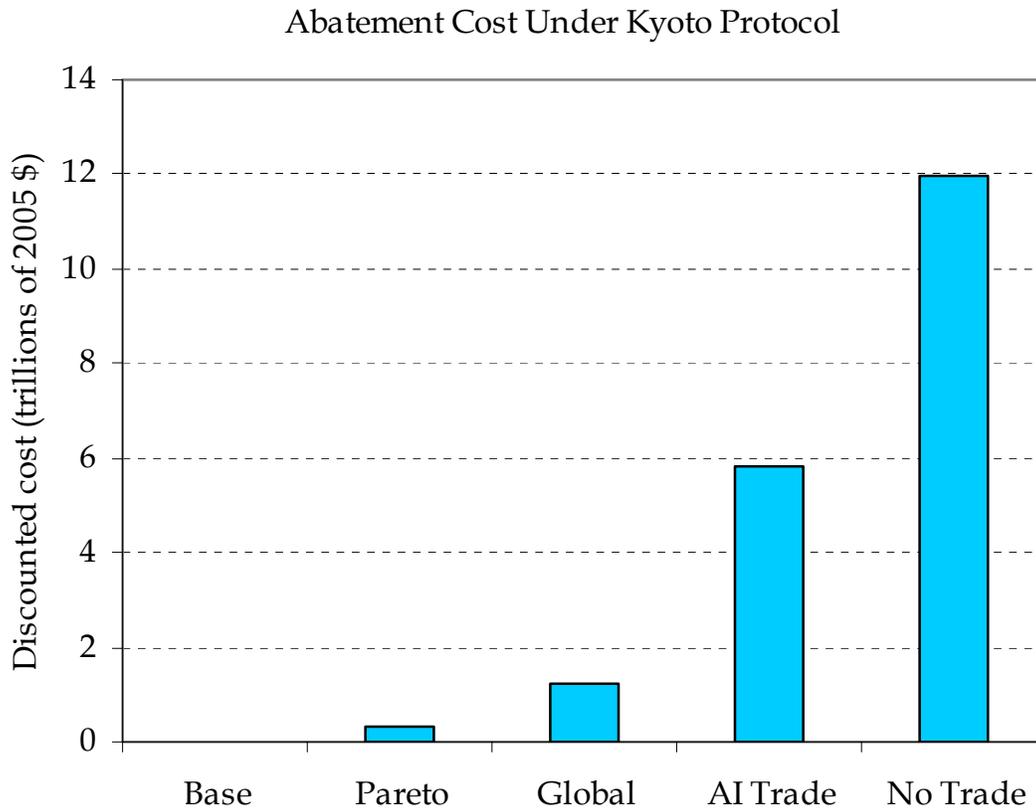
Source: See Figure 2.

Abatement Cost Under Kyoto Protocol

Figure 6. Abatement Costs under Different Implementation Strategies of the Kyoto Protocol in the RICE-2001 Model

The estimates are the discounted value of the costs of abatement and exclude any environmental benefits. Costs are discounted to 2005 and are in 2005 U.S. dollars. The results use the revised RICE-2001 model. The *Base* case is with no restraints on emissions. The *Pareto* case is one that balances costs and benefits over time. *AI trade* is the basic Kyoto Protocol with full Annex I trading. *Global* is the case where the emissions under the AI Trade case are traded among all countries. *No Trade* allows no emissions trading among the four major regions of Annex I.
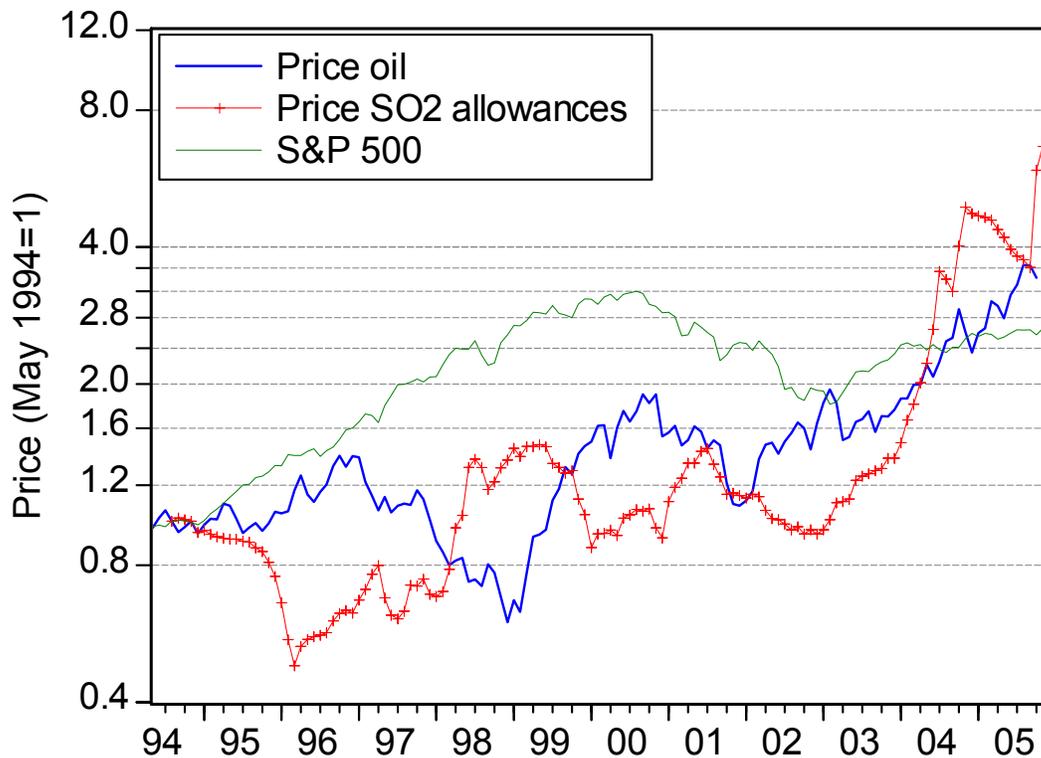
Source: See Figure 2.

Figure 7. Prices of sulfur emissions permits are highly volatile, 1994-2005

One of the potential concerns with the current structure of the Kyoto Protocol is that it will induce great volatility in the prices of permits. The volatility can be seen in the history of SO_2 permit prices, which have been much more volatile than oil prices or stock prices. Note that some SO_2 price changes reflect regulatory changes, particularly after 2003.

Source: Oil prices and CPI from DRI. Price of SO_2 permits from Denny Ellerman, EPA, and trade data.

Appendix. The revised RICE-2001 model

The RICE model (Regional Integrated model of Climate and the Economy) is an integrated or "end-to-end" model that analyzes the major economic tradeoffs involved in global warming. It uses the framework of optimal economic growth theory and incorporates emissions and climate modules to analyze alternative paths of future economic growth and climate change. This appendix provides a brief overview of the RICE-99 model and describes the changes incorporated in the RICE-2001 model. The RICE-99 model is fully documented in the published literature and on the Internet.[26]

In the RICE-99 model, the world is composed of eight regions (the U.S., Western Europe, other high-income countries, China, Eastern Europe and the former Soviet Union, middle-income countries, lower-middle-income countries, and low-income countries). Each region is assumed to have a well-defined set of preferences by which it chooses its path for consumption over time. The welfare of different generations is combined using a social-welfare function that applies a pure rate of time preference to different generations. Nations are then assumed to maximize the social-welfare function subject to a number of economic and geophysical constraints. The decision variables that are available to the economy are consumption, the rate of investment in tangible capital, and the climate investments, represented by reductions of emissions of greenhouse gases.

The model contains both a traditional economic sector, similar to that found in many economic models, and a geophysical module designed for climate-change modeling. Each region is endowed with an initial stock of capital and labor and an initial and region-specific level of technology. Population growth and technological change are exogenous in the baseline model, while capital accumulation is determined by optimizing the flow of consumption over time. The energy sector is modeled as producing and consuming "carbon-energy," which is the carbon equivalent of energy consumption and is measured in carbon units. Technological change takes two forms: economy-wide technological change and carbon-energy saving technological change.

The environmental part of the model contains a number of geophysical relationships that link together the different forces affecting climate change. These involve a carbon cycle, a radiative forcing equation, climate-change equations, and a climate-damage relationship. Endogenous emissions are limited to industrial CO_2, which is a joint product of carbon-energy. Other contributions to global warming are taken as exogenous. Climate change is represented by global mean surface temperature,

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[26] See Nordhaus and Boyer, *Warming the World*, *op. cit.* Full documentation is available on the Internet at
www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm .

and the relationship between radiative forcing and climate uses the consensus of climate modelers and a lag derived from coupled ocean-atmospheric models. The economic impacts of climate change uses a willingness-to-pay approach and relies on detailed sectoral estimates for thirteen major regions of the world; the model includes both market and non-market impacts of climate change along with an estimate of the potential impact of abrupt climate change.

Changes are introduced into the revised RICE-2001 model only for the U.S. and Western Europe. For the U.S., recent data indicate an increase in long-term productivity growth and potential output. Consequently, the estimated rate of total factor productivity (TFP) growth has been increased from 0.38 percent per year to 0.98 percent per year in the first decade with declining changes in subsequent decades; part of this reflects changes in output measurement and part is genuine productivity acceleration. The initial increase in the efficiency of carbon-energy services was increased from 1.13 percent per year to 1.33 percent per year to reflect measurement changes in output. According to the baseline projections, U.S. industrial carbon emissions for the period centered on 2005 over that centered on 1995 are estimated to grow at 1.7 percent per year.

Similarly, trend output growth in Western Europe appears to have increased relative to earlier forecasts. We have therefore increased estimated TFP growth in Western Europe from 0.41 percent per year to 0.98 percent per year in the first decade, with appropriate adjustments thereafter. There is no apparent change in the efficiency growth of energy services in Western Europe, so that parameter was unchanged. All other parameters were kept at the levels assumed in the RICE-1999 model.

The recent apparent sharp decline in carbon dioxide emissions in China will have little effect on the analyses of the Kyoto Protocol in the RICE model because the model envisions sharp increases in energy efficiency in the baseline case. Holding Chinese emissions constant over the next century has virtually no effect on the estimated carbon prices.

The RICE-2001 model is available in a spreadsheet version on the Internet at www.econ.yale.edu/~nordhaus/homepage/ dicemodels.htm .