To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming

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How can countries best coordinate their policies to slow global warming? This study reviews different approaches to the political and economic control of global public goods such as global warming. It compares quantity-oriented mechanisms like the Kyoto Protocol with price-type control mechanisms such as internationally harmonized carbon taxes. The analysis focuses on such issues as the relationship to ultimate targets, performance under conditions of uncertainty, volatility of induced carbon prices, the inefficiencies of taxation and regulation, potential for corruption and accounting finagling, and ease of implementation. It concludes that price-type approaches such as carbon taxes have major advantages for slowing global warming.

Before discussing different approaches, it will be useful to sketch the scientific basis for concerns about global warming. As a result of the buildup of atmospheric greenhouse gases (GHGs), it is expected that significant climate changes will occur in the coming decades and beyond. The major industrial GHGs are carbon dioxide (CO_2), methane, ozone, nitrous oxides, and chlorofluorocarbons (CFCs). Using climate models as well as examining past climate variations, scientists expect significant climatic changes in the coming years. Current estimates are that an increase that doubles the amount of CO_2 or the equivalent in the atmosphere compared with preindustrial levels will, in equilibrium, lead to an increase in the global surface temperature of 1.5–4.5°C, an increase in precipitation and evaporation, and a rise in sea levels of 10–90 cm over this century. Some models also predict regional shifts, such as hotter and drier climates in midcontinental regions, such as the U.S. Midwest. Climate monitoring indicates that the predicted global warming is occurring in line with scientific predictions.[1]

While scientists have been analyzing global warming for more than half a century, nations took the first formal steps to slow global warming only about fifteen years ago, under the United Nations Framework Convention on Climate Change (FCCC). The first binding international agreement on climate change, the Kyoto Protocol, came into effect in

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[1]Extensive discussions on this subject are contained in reports by the Intergovernmental Panel on Climate Change, especially IPCC 2001, with evidence for recent warming in Hansen et al. (2006).

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2005, and the first period for emissions reductions, 2008–2012, is at hand. The framework for implementing the protocol is most solidly institutionalized in the European Union's Emissions Trading Scheme (EU ETS), which covers almost half of Europe's CO_2 emissions (EU ETS 2006; Klepper and Peterson 2005).

Notwithstanding this apparent success, the Kyoto Protocol is widely seen as a troubled institution. Early problems appeared with the failure to include the major developing countries, the lack of an agreed-upon mechanism to include new countries, and an agreement that is limited to a single period. The major blow came when the United States withdrew from the treaty in 2001. Whereas 65 percent of the 1990 world emissions were included in the original protocol, that number had declined to 32 percent in 2002 with the withdrawal of the United States and strong economic growth in noncovered countries, largely the developing nations of the world. Strict enforcement of the Kyoto Protocol is likely to be observed primarily in those countries and industries covered by the EU ETS. These emissions today account for about 8 percent of global emissions. If the current protocol is extended at the current reduction rates, models indicate that it will have little impact on global climate change (Nordhaus and Boyer 1999; Manne and Richels 1999; Nordhaus 2001; MacCracken et al. 1999).

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. Most global-warming policies adopted by U.S. states or considered by the U.S. federal government contain some mixture of emissions limits and technology standards. Is the Kyoto Protocol a viable long-term approach to this long-term problem? Are there alternatives that might reduce global warming more efficiently? I consider these questions in this article.

The first section describes the political and economic issues raised by global public goods like global warming. It suggests that attempts to coordinate sovereign governments raise thorny problems beyond those involved in most national pollution problems. The next section describes the major mechanisms available to coordinate dealings with global public goods. The subsequent section describes the three fundamental issues that must be resolved in any regime to address climate change—the level of emissions reductions, the distributions of emissions reductions across countries, and the mechanisms to encourage participation of low-income countries. I then describe the price-type approach of harmonized carbon taxes. The penultimate section discusses specific concerns such as how well different approaches meet ultimate objectives, the problem of setting baselines for prices and quantities, treatment of uncertainty in different approaches, the potential for great volatility in the market prices of carbon under quantitative systems, public finance questions, problems of corruption, and administrative issues. I close with a summary of the major issues.

Policies for Global Public Goods

Global warming is a member of a special type of economic activity known as *global public goods.* These are economic or other activities whose impacts are indivisible and whose influences are felt around the world rather than affecting one nation, town, or family. These are not new phenomena. However, they are becoming increasingly prevalent because of rapid technological change and the rapid decline in transportation and communication costs. What makes global public goods different from other economic activities is that there exist only weak economic and political mechanisms for solving these issues efficiently and effectively.

Dealing with global public goods has been an increasingly important feature of international relations. Aside from global warming, important examples are nuclear proliferation, infectious diseases, intellectual property rights, international trade in goods and services, macroeconomic stability, fisheries, endangered species, and transnational terrorism. We have only to think about recent crises such as those involving weapons of mass destruction, the AIDS epidemic, international financial crises, and the threat of avian flu to realize how prevalent global public goods are. A little further reflection will indicate that nations have had only modest success in agreements to deal with global public goods. There are but a few examples of regimes that manage international public goods effectively, such as those managing international trade disputes (today primarily through the World Trade Organization) and the CFC protocols.

There are major governance issues involved in dealing with global public goods. It is necessary to locate decision making at a level in the hierarchy between the household and a weak or nonexistent world government that can efficiently coordinate solutions. This is a particularly thorny problem for global public goods because global coordination is required. The need for global decision making leads to the Westphalian dilemma. Under international law as it developed in the 1648 Treaty of Westphalia and evolved in Western Europe, obligations may be imposed on a sovereign state only with its consent. Because of the structure of international law, therefore, there is no legal mechanism by which disinterested majorities or even super majorities of countries can coerce noncooperating countries to provide for global public goods. In other words, the Westphalian system is one that allows free-riding. Therefore, we must take entirely different approaches to global public goods compared with those taken for regional, national, or local public goods.

Economic and Focal Public Goods

Looking at the varieties of global public goods, I want to focus on those I will call economic public goods. These activities involve huge numbers of economic agents in a large number of countries, in which the costs and benefits of action do not indicate any obvious focal policy or technological fix. By contrast, I denote as focal public goods those activities in which good policies appear obvious or consensual to most people; for example, it does not take much persuasion to convince people that a reasonable standard is zero AIDS, zero smallpox, zero financial collapses, zero nuclear meltdowns, or zero nuclear explosions.

With economic public goods, by contrast, it is 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 fisheries (where the point of overfishing is difficult to calculate), pollution (where zero pollution is prohibitively expensive), and global warming (where it is apparent that the optimal abatement is today somewhat short of 100 percent of GHG 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. Similarly, 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.

Specific Mechanisms to Deal with Global Public Goods

Nations have forged a variety of frameworks for dealing with global public goods and other transnational issues, employing a wide variety of instruments or techniques (Barrett 2003). A partial list is (i) noncooperative, market-based, or laissez-faire approaches (as is currently the case for production of most goods and services as well as for some potential global issues such as asteroid defense); (ii) aspirational or hortatory agreements that urge countries to undertake actions (e.g., the FCCC) or nonbinding voluntary agreements (e.g., the institutional regime created in the 1980s to clean up pollution in the North Sea); (iii) specific and binding treaties, legal contracts among sovereign nations, which are the standard way to deal with international issues (currently in effect for CFCs and many other global environmental agreements); (iv) agreements embedded in broader international institutions or agreements (exemplified when Western nations forced developing countries to accept strong patent protection under the last multilateral trade negotiations); and (v) 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 World Trade Organization [WTO], and in some the international financial institutions). This array of international institutions reminds us that although global warming is a new problem, the problems of international political economy raised by global warming are quite ancient.

When dealing with economic public goods like global warming, it is necessary to reach through governments to the multitude of firms and consumers who make the vast number of decisions that affect the ultimate outcomes. There are two major mechanisms that can be employed—quantitative limits through government fiat and regulation, and price-based approaches through fees, subsidies, or taxes.[2]

In the global-warming context, quantitative limits set targets on the time path of GHG emissions of different countries. Countries then can administer these limits in their own fashion, and the mechanism may allow transfer of emissions allowances among countries, as is the case under the Kyoto Protocol. This approach has limited international experience under existing protocols such as the CFC mechanisms and broader experience under national trading regimes such as the U.S. SO_2 allowance-trading program.

The second 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 considerable national experience for environmental markets in such areas as the U.S. tax on ozone-depleting chemicals. On the other hand, the 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.

[2]This distinction is drastically simplified. For a nuanced discussion including variants and hybrids, see Aldy, Barrett, and Stavins (2003) and the many references and proposals therein.

Major Issues in Any International Climate-change Regime

Any climate-change regime must face three fundamental issues—the overall level and trajectory of emissions reduction (reflected in a control rate or a market price of carbon emissions), the distribution of emissions reductions across countries, and the need for mechanisms to encourage participation of low-income countries and other reluctant countries. Each of these issues is very contentious.

The Overall Level and Trajectory of Emissions Reduction

Because global warming is a global public good, the key environmental issue is global emissions, and the key economic issue is how to balance costs and benefits of global emissions reductions. Climate change depends only upon total GHG emissions and the time path of emissions, not on the geographic location of emissions. Moreover, the impacts depend primarily upon cumulative emissions that remain in the atmosphere, not on the annual flow of emissions.

Under a price approach, the level of emissions is determined indirectly by the level of the tax or penalty levied on carbon emissions. Under a quantitative approach, the level of emissions is directly chosen. However, a market economy is likely to develop markets for emissions permits, and a market price will therefore emerge. An economist will naturally examine the price in either case, and the first issue can be rephrased as: What is the level of the market price of carbon emissions that is consistent with the regime?

A quantitative measure of the tightness of emissions controls is the value of the "carbon price," "carbon tax," or the "social cost of carbon." The carbon price measures the market price attached to the right to emit 1 ton of carbon through burning fossil fuels or other activities. For calibration purposes, if a hundred-dollar-per-ton carbon tax were to be levied on gasoline, that would raise the price by twenty cents per gallon.[3]

The key economic question under any regime is whether the price is likely to be high or low. We can examine these questions quantitatively using computerized models built to study the economics of global warming. These models are called "integrated-assessment models," or IAMs. The use of IAMs has blossomed over the last two decades, and there are now dozens of global models and even larger numbers of models that apply to individual countries.

Carbon prices in efficient emissions reductions

The question of the "optimal" level of emissions reductions is undoubtedly the most difficult and controversial question in the economics of global warming. In a series of studies, my coauthors and I have estimated cost and damage functions and estimated "optimal" or efficient emissions reductions to slow global warming. The results discussed here use the "RICE model" (regional integrated model of climate and the economy), which

[3]Scientists and economists have customarily measured carbon prices in terms of carbon weight, and I follow that convention. Current emissions-trading programs generally quote in terms of carbon dioxide weight, which has a mass 3.67 times that of carbon. To convert from the carbon units to the CO_2 units, multiply the mass or divide the price by 3.67.

is an IAM that analyzes the major economic trade-offs involved in global warming. It uses the framework of economic growth theory and incorporates emissions and climate modules to analyze alternative paths of future economic growth and global warming.

The latest calculation in the deterministic aggregate RICE model suggests that a 2010 carbon price of around $17 per ton carbon in 2005 prices—rising to $70 per ton in 2050—would efficiently balance the costs and benefits of emissions reductions, that is, maximize the present discounted value of benefits minus costs.

It must be recognized that this estimate of the efficient carbon tax is unlikely to capture all the nonmarket aspects of global warming (such as effects on ecosystems), problems of uncertainty and risk aversion, and the potential for "dangerous interferences" with many global processes.[4] Nonetheless, it does describe a path that recognizes that countries care about their economic development as well as future costs of global warming.

Many other estimates exist for the appropriate market prices of carbon. At the high end is the social cost of carbon proposal in the UK government's Stern Review (2006) of $310 per ton of carbon; the very bottom of $0 is implicit in the policies of global-warming skeptics and the environmental skeptics in the G.W. Bush Administration. However, the relatively low current efficient market price of carbon found in the RICE model was one of the major conclusions in a review of IAMs: "Perhaps the most surprising result is the consensus that given calibrated interest rates and low future economic growth, modest controls are generally optimal" (Kelly and Kolstad 1999).

Emissions reductions and carbon prices in the Kyoto Protocol

Several studies have estimated the economic impacts of the Kyoto Protocol. Modeling estimates indicate that global emissions under the Kyoto Protocol as actually operating would be very close to a "no-controls" baseline, that is, a world without policy-induced GHG emissions reductions. Estimates from the RICE model indicate that global CO_2 emissions in a no-controls world would grow by about 27.5 percent between 1990 and 2010, whereas under the current version of the Kyoto Protocol global emissions growth over the same time period would be around 26 percent. In other words, the analysis indicates that global emissions in 2010 would be 1.5 percent lower than without controls (Figure 1).

Moreover, the RICE model and other studies estimated that the Kyoto Protocol would lead to highly differentiated prices and therefore to an inefficient allocation of abatement across countries (Manne and Richels 1999, 2001; MacCracken et al. 1999; Nordhaus and Boyer 2000; Nordhaus 2001). With the U.S. withdrawal from the protocol, global emissions reductions and carbon prices are projected to be much lower than in the original version. RICE model results indicate that the carbon price in 2010 would be $41 per ton of carbon with the United States and $18 without the United States. With the United States out of the picture, the price of permits in Europe would be dramatically lower because the required emissions reductions for the participants would be much smaller.

[4]This term is motivated by the FCCC, 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." (United Nations Framework Convention on Climate Change at http://unfccc.int/2860.php).

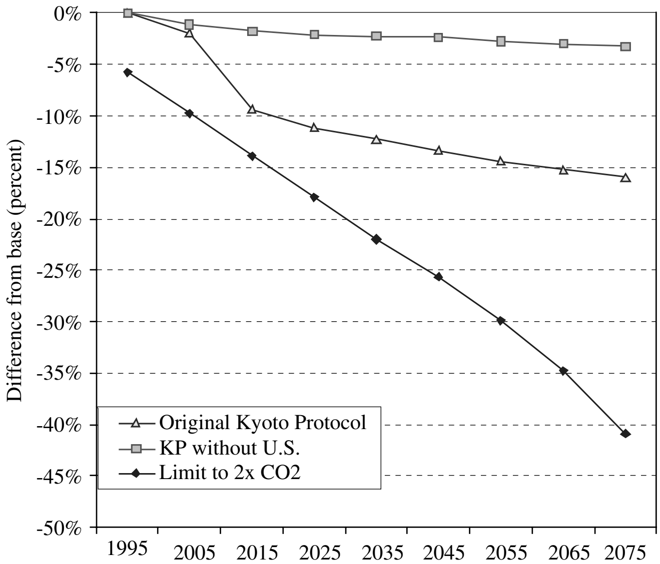

Figure 1. Estimated emissions reductions for different regimes. Numbers are for total global industrial CO_2 emissions and measure the percentage reduction relative to a baseline path of no emissions reductions. The Kyoto paths are "Kyoto forever" and assume that countries freeze their emissions at the 2008–2012 average after the first period with no extension in participation. The "Original Kyoto Protocol" shows the impact of the protocol with United States participation. "KP without United States" shows the impact of removing the United States from the protocol. The "Limit to $2\times$ CO_2" shows the emissions reductions that would minimize the discounted costs of limiting CO_2 concentrations to double preindustrial concentrations. The estimates are for the decades centered on the year shown on the horizontal axis. Source: Nordhaus 2001.

The Distribution of Emissions or Emissions Reductions among Countries

What should be the distribution of emissions reductions among countries, and how should the costs be allocated? These questions apply to differences among high- and low-income countries, among high- and low-emitting countries, and among high- and low-vulnerability countries.

Economics offers a simple, unambiguous, but elusive answer: emissions reductions should be carried out in the most efficient 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 (discussed in this section), while the second half refers to sharing the costs among countries (which is discussed in the next section).

Emissions reductions will be efficient or "cost effective" if the marginal costs of emissions reductions are equalized across space and, with appropriate discounting, across time. The spatial component of efficiency ("where efficiency") is that the marginal cost of reductions should be equalized across all countries, industries, and sources. The temporal component ("when efficiency" or intertemporal efficiency) is more complicated. When efficiency requires that the profile of emissions be timed to attain the ultimate goal (whether the goal be concentrations or temperature stabilization or a dynamic cost–benefit criterion). In simple dynamic models, intertemporal efficiency requires that the market price of carbon (equal to the marginal cost of emissions reductions) grows over time at a rate equal to the

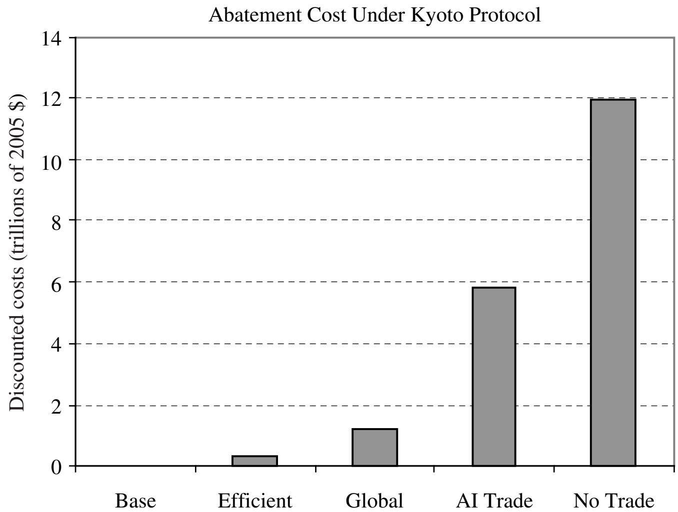

Figure 2. Estimated abatement costs for different implementation strategies of the Kyoto Protocol. This figure shows the discounted value of the costs of abatement and excludes any environmental benefits. Annex I includes high-income countries plus the "transition" economies of Eastern Europe and the former Soviet Union. Costs are discounted to 2005 and are in 2005 U.S. dollars. The *Base* case is with no restraints on emissions and is by definition zero. The *Efficient* case maximizes discounted net benefits, including environmental benefits. *Global* is the case where the emissions under the Annex I countries of the Kyoto Protocol are freely traded among all countries. *AI trade* is the basic Kyoto Protocol with full trading of emissions allowances among Annex I countries only. *No Trade* allows no emissions trading among the four major regions of Annex I. The underlying model is described in Nordhaus and Boyer 2000, updated in Nordhaus 2001.

"real carbon interest rate," which is approximately equal to the real interest rate less the disappearance rate of CO_2 from the atmosphere.

The Kyoto Protocol is defective on both spatial and temporal 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 of the cost-effectiveness criterion). The two largest emitters (the United States and China) are not included in the current protocol. Figure 2 shows the most recent estimates of abatement costs under different trading regimes for the original Kyoto Protocol using the RICE model. 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.

Mechanisms to Encourage Participation

How should the economic burden of reducing emissions be shared among countries? "All politics are distributional," is a maxim of American politics. This is no less true of the politics of international environmental agreements. Neither science nor economics can provide a "correct" answer to the question of how to share the burden of reducing emissions. Disinterested observers might argue that the costs should be allocated on the basis of ability to pay, with richer countries and generations paying a larger fraction of the costs. Interested

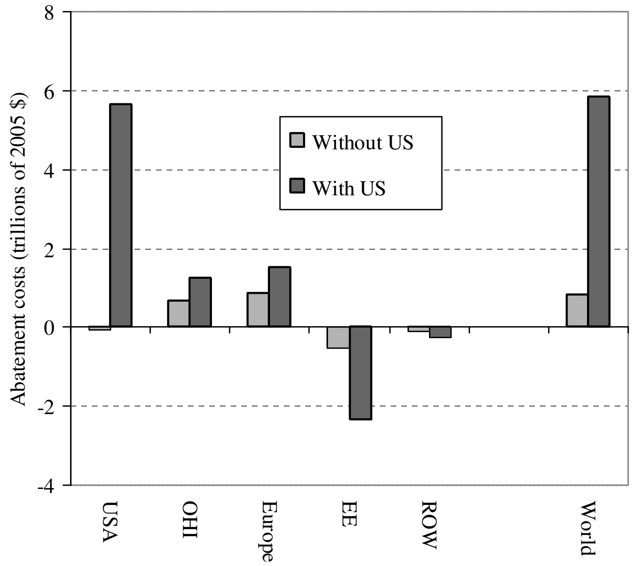

Figure 3. Abatement costs of Kyoto Protocol with and without U.S. participation. This figure shows the discounted value of the costs of abatement (emissions reductions) and excludes any environmental benefits. The first four regions are participants and the last region (ROW) sums the impacts for all non-participants. The burden of abatement shifts greatly with the U.S. withdrawal from the Kyoto Protocol. Source: Nordhaus 2001. OHI, other high-income countries, including Japan and Canada; Europe, primarily the EU; EE, Eastern Europe and the countries of the former Soviet Union; ROW, the rest of the world.

observers, such as negotiating countries, want to pay as little as possible, and are unlikely to participate voluntarily unless they have a positive net benefit.

The Kyoto Protocol has an arbitrary allocation of burdens and transfers because it generally used 1990 emissions as a base year when setting targets in the negotiations during 1997. Consequently, those countries with high emissions in 1990 (such as Russia) are advantaged while those whose emissions have subsequently grown rapidly (such as the United States) are disadvantaged.

The result of the initial allocation is that the Kyoto Protocol was hampered at its inception by a distribution of abatement costs that was weighted heavily toward the United States Figure 3 shows the RICE model estimates of the costs of abatement for different regions with and without U.S. participation. This study suggested that the United States would bear a large fraction of the costs of implementing the protocol. Indeed, the estimated net benefits for the United States, including environmental benefits (not shown), were negative. At the other extreme, it seems likely that Russia was induced to participate because it would have excess allowances that could be exported.

Just as thorny are questions involving the participation of low-income countries. Efficiency requires full participation of low-income counties in emissions reductions; indeed some of the most economical emissions reductions can be found in low-income countries. But including low-income countries is challenging for many reasons—fairness, development priorities, and pure bargaining strategies. In any mechanism, it seems likely that high-income countries will provide financial and technical assistance to low-income countries to induce participation.

In both the FCCC and the Kyoto Protocol, developing countries were excluded from any obligations to reduce emissions. This approach was probably a fundamental mistake. It is 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" principle of an income tax system. Part of the challenge is designing a fair graduation procedure; another part is overcoming the Westphalian dilemma of inducing countries to participate when graduation day comes.

Price Approaches to Climate Change

Attempts to address climate change through prices rather than quantities have been discussed in a handful of papers in the economics literature (see Cooper 1998; Pizer 1998; Victor 2001; Aldy, Barrett, and Stavins 2003), but much careful analysis remains to be done. I will highlight a few of the details.

For concreteness, I will discuss a mechanism called harmonized carbon taxes (HCT). Under this approach, there are no binding international or national emissions limits. Rather, countries would agree to penalize carbon emissions at an internationally harmonized "carbon price" or "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. The carbon price might be determined by estimates of the price necessary to limit GHG concentrations or temperature changes below some level thought to be "dangerous interference," or it might be the price that would induce the efficient level of control. Unlike the quantitative approach under the Kyoto Protocol, there would be no country emissions quotas, no emissions trading, and no base period emissions levels. Because carbon prices would be equalized, the approach would 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.

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 developing countries under an HCT are important details that require discussion and refinement. 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 dealt with problems of tariffs, subsidies, and differential tax treatment for many years. Some of the thorny administrative issues are discussed below.

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 clothing"—putting ceilings on the price of emissions-trading permits by combining a tradable permit system with a government promise to sell additional permits at a specified price (McKibbin and Wilcoxen 2002; Aldy, Barrett, and Stavins 2003). Price caps were considered and rejected by the Clinton Administration in its preparation for the negotiations on the Kyoto Protocol.

The present analysis focuses on the pure strains of the two systems to keep the analysis within manageable limits. From a practical point of view, mixed systems sometimes revert to their archetypes. For example, even though the Kyoto Protocol was designed to allow complete trading among the participants, there have been strong pressures to limit trading and force countries to make much of their reductions domestically. 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 imposed through quotas are extremely durable.

Comparison of Price and Quantity Approaches

The Kyoto Protocol lacks any connection to ultimate economic or environmental policy objectives. 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 relationship to an economically oriented strategy that would minimize the costs of attaining environmental and economic objectives.

Price-type systems such as taxes have a mixed record of efficiency. In this context, the ideal system for a harmonized carbon tax is relatively simple, as described above. Because of its conceptual simplicity, it might prove simpler to design an efficient tax than an efficient quantity mechanism.

Setting Baselines for Prices and Quantities

Quantity limits are particularly troublesome where targets must adopt to growing economies, differential economic growth, uncertain technological change, and evolving science. These problems are especially prominent under the Kyoto Protocol, which set its targets thirteen years before the date on which the controls become effective (2008–2012), and used baseline emissions from twenty years before the control period. Base year emissions have become increasingly as obsolete as the economic and energy structures, and even political boundaries of countries have changed.

The baselines for future budget periods and for new participants will present deep problems for extensions of a quantity regime like the Kyoto Protocol. A natural baseline for the post-2012 period would be a no-controls level of emissions. That level is in practice impossible to calculate or predict with accuracy for countries with abatement policies 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 or penalty. 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. The question of existing energy taxes may raise similar complications, and I address these below. Moreover, there is no asymmetry between early joiners and late joiners, and early participants are not disadvantaged by having their baseline adjusted downward.

Treatment of Uncertainty

Uncertainty pervades climate-change science, economics, and policy. One key difference between price and quantity instruments is how well each adapts to deep uncertainty. A major result from environmental economics is that the relative efficiency of price and quantity regulation depends upon the nature—and more precisely the degree of non-linearity—of costs and benefits (Weitzman 1974). If costs are highly nonlinear compared to benefits, then price-type regulation is more efficient; conversely, if the benefits are highly nonlinear while the costs are close to linear, then quantity-type regulation is more efficient.

While this issue has received scant attention in the design of climate-change policies, the structure of the costs and damages in global warming gives a strong presumption to price-type approaches. The reason is that the benefits are related to the stock of GHGs, 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 close to independent of the current level of emissions reductions (Pizer 1999; Hoel and Karp 2001). This combination means that emissions fees or taxes are likely to be much more efficient than quantitative standards or tradable quotas when there is considerable uncertainty. This insight applies far beyond global warming to any stock public good.

Volatility of the Market Prices of Tradable Allowances

Uncertainties affect prices. Because supply, demand, and regulatory conditions evolve unpredictably over time, quantity-type regulations are likely to cause volatile trading prices of carbon emissions. Price volatility for allowances is likely to be particularly high because of the complete inelasticity of the supply of permits along with highly inelastic demand for permits in the short run.

The history of European trading prices for CO_2 illustrates the extreme volatility of quantity systems. Over 2006, the range of trading prices has been from \$44.47 to \$143.06 per ton carbon (Point Carbon 2006). The prices of allowances fell by more than 70 percent in one month because of new regulatory information.

More extensive evidence with the trading of quantitative environmental allowances comes from the history of the U.S. sulfur dioxide (SO_2) emissions-trading program. This program includes an annual auction conducted by the EPA as well as private markets, in which firms and individuals can buy and sell allowances. The comparison between SO_2 prices and carbon trading prices is useful because of the similar economic characteristics of the respective markets. Both markets are ones in which the supply is fixed or near-fixed in the short run. Moreover, for each market, the demand is highly inelastic because it involves the substitution between a fuel (such as coal) and other inputs, where the technology is relatively inflexible in the short run and substitution is therefore limited. To some extent, the volatility can be moderated if an agreement allows banking and borrowing, meaning that countries can draw from future emissions allowances, or save allowances for the future.

But programs are unlikely to allow borrowing, and banking provides only limited relief from price volatility.

We can gain some insight into the likely functioning of CO_2 allowances by examining the historical volatility of the price of SO_2 allowances. Spot SO_2 prices at the annual EPA auction have varied from a low of \$66 per ton in 1996 to a high of \$860 per ton in 2005. Futures prices have varied by a factor of 4.7 (EPA 2006). If we look at the private market, we find that allowance prices have varied by a factor of 69 in the 1995–2006 period and by a factor of 12 in the 2001–2006 period. Some changes have been induced by changes in regulatory policies, but that feature would be relevant for the carbon market as well.

We can obtain a more precise measure of variability by calculating the statistical "volatility" of the prices of SO_2 emissions allowances and comparing them with other volatile prices. Volatility measures the average absolute month-to-month change, and is a common approach to indicating the variability and unpredictability of asset prices. Figure 4 shows the estimated volatility of four prices for the period 1995–2005: the consumer price index, stock prices, SO_2 allowance prices, and oil prices. SO_2 prices are much more volatile than stock prices (or than the prices of other assets such as houses, not shown); they are vastly more volatile than most consumer prices; and their volatility is close to that of oil prices.

Such rapid fluctuations are costly and 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 United States during the monetarist experiment of 1979–82, when the Federal Reserve targeted quantities (monetary aggregates) rather than prices (interest rates). During that period, interest rates were extremely volatile. In part owing to the increased volatility, the Fed changed back to a price-type approach after a short period of experimentation (Poole 1970). This experience suggests that a regime of strict quantity

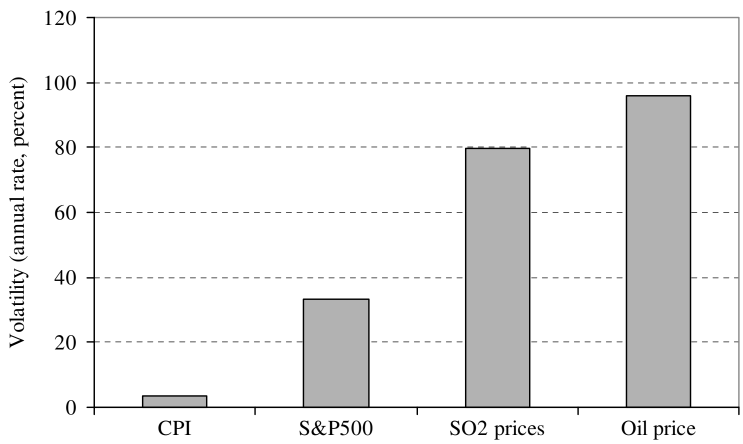

Figure 4. Prices of sulfur emissions allowances show high volatility. This figure shows the estimated volatility of four prices over the 1995–2006 period. These are, from left to right, the consumer price index (CPI), the stock price index for the Standard and Poor 500 (S&P500), the price of U.S. SO_2 allowances (SO_2 prices), and the price of crude oil (Oil price). Volatility is calculated as the annualized absolute logarithmic month-to-month change. Source: Oil prices, CPI, and stock prices from DRI database available at Yale University. Prices of SO_2 permits are spot prices provided by Denny Ellerman and reflect the trading prices.

limits might have major disruptive effects on energy markets and on investment planning, as well as on the distribution of income across countries, inflation rates, energy prices, and import and export values. It might consequently become extremely unpopular with market participants and economic policymakers.

Public Finance Questions

Another important merit of carbon taxes is the strong fiscal-policy advantage of using revenue-raising measures. When tax or regulatory restrictions raise goods prices, this increases inefficiency losses from the existing tax system. The reasoning is that the existing tax and regulatory system raises prices above efficient levels. Adding further taxes or regulations to existing ones increases the inefficiency or "deadweight loss" of the existing system and should be counted as part of the additional costs of global-warming policy. This effect is the "double burden" of taxation, analyzed in the theory of the "double dividend" from green taxes (Goulder, Parry, and Burtraw 1997; Goulder and Bovenberg 1996.)

If the carbon constraints are imposed through taxes, and the revenues are returned by reducing taxes on other goods or inputs, then the increased efficiency loss from taxation can be mitigated, so that there is no net increase in deadweight loss. If the constraints under a quantity-based system are imposed by allocations that do not raise revenues, however, then there is no mechanism to mitigate the increased deadweight loss. This is an important issue, as the inefficiency losses can be as large as abatement costs.

While it is possible that emissions permits will be auctioned (thereby generating revenues with which the tax burden can be mitigated), practice suggests that most of the permits would be allocated at zero cost to "deserving" parties, or distributed to reduce political resistance. In the cases of SO_2 allowances and CFC production allowances, virtually *all* the permits were allocated at no cost to producers. The major conclusion 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.

Rents, Corruption, and the Resource Curse

An additional question, applying particularly to international environmental agreements, concerns the administration of programs in a world in which governments vary in terms of honesty, transparency, and effective administration. Quantity-type systems are much more susceptible to corruption than price-type regimes. An emissions-trading system creates valuable assets in the form of tradable emissions permits and allocates these to countries. Limiting emissions creates a scarcity where none previously existed. It is a rent-creating program. The dangers of quantity as compared to price approaches have been demonstrated frequently when quotas are compared with tariffs in international trade interventions.

Rents lead to rent-seeking behavior. Additionally, resource rents may increase unproductive activity, civil and international wars, and slow economic growth—this being the theory of the "resource curse" (Sachs and Warner 1995; Torvik 2002). The scarce permits can be used by the country's leaders for nonenvironmental purposes rather than to reduce emissions. Dictators and corrupt administrators could sell part of their permits, and pocket the proceeds.

Calculations suggest that tens of billions of dollars of permits may be available for foreign sale from Russia under the Kyoto Protocol. Given the history of privatizing valuable public assets at artificially low prices, it would not be surprising if the carbon market became tangled in corrupt practices, undermining the legitimacy of the process. We might also imagine a Kyoto Protocol extended to developing countries. Consider the case of Nigeria, which had carbon emissions of around 100 million tons in recent years. If Nigeria were allocated tradable allowances equal to recent emissions and could sell them for $20 per ton of carbon, this would raise around $2 billion of hard currency annually—in a country whose nonoil exports in 2000 were only $600 million.

Problems of financial finagling are not limited to poor, weak, or autocratic states. Concerns arise in the wake of the recent accounting scandals in the United States. A cap-and-trade system relies upon accurate measurement of emissions or fossil fuel use by sources in participating countries. If firm A (or country A) sells emissions (or carbon-content) permits to firm B (or country B), where both A and B are operating under caps, then it is essential to monitor the emissions (or fuel use) of A and B to make sure that their emissions (fuel use) are 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. Incentives to evade emissions limitations in an international system are even stronger than the incentives for tax evasion. Tax cheating is a zero-sum game for the company and the government, while emissions evasion is a positive sum game for the two parties.

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. There is no new rent-seeking opportunity. Any revenues would need to be raised by taxation on domestic consumption of fuels, and a carbon tax would add absolutely nothing to the rent-producing instruments that countries have today.

Administrative and Measurement Issues

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. (Victor 2001, 86)

Such concerns are serious. 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 Poland imposed a fifty-dollar carbon tax, which would fall primarily on coal. It might at the same time increase coal subsidies 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 the net taxation of carbon fuels, including all taxes and subsidies on energy products, but not to go beyond this to indirect, embodied impacts (i.e., carbon used to produce inputs into production) outside of 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. A final issue is how to count initial taxes.

Obtaining data on country tax rates

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:

> 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. (Cooper 1998)

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 nonmarket economies or in sectors in which fuels are allocated directly rather than by the price mechanism. Direct allocation is becoming the exception rather than the rule in the world today, however.

Conceptual issues in measuring tax rates

The second issue, calculating the effective carbon tax from the underlying data, is a technical economic issue. Calculations would require 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 control system. 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 do not involve indirect or embodied emissions.

To go beyond first-round calculations to indirect effects 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 need to calculate effective taxes under a set of guidelines that would evolve under quasi-legal procedures. Many of these issues are discussed in the literature on ecological taxes (von Weizsäcker and Jesinghaus, 1992).

How to count initial carbon taxes

A final 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. Nordhaus and Boyer calculated that, even without CO_2 taxes, Europe is taxing carbon at a rate of approximately one hundred dollars per ton of carbon more than the United States (Nordhaus and Boyer, 2000). 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 impose even modest carbon taxes.

Conclusion

We are just beginning to understand and cope with the "great geophysical experiment" of global warming (Ravelle and Seuss, 1957). In this article, I suggest that price-type approaches such as HCTs are more efficient instruments than quantity approaches like those found in the Kyoto Protocol. Under the tax approach, countries set market penalties on GHG emissions at levels that are equalized across different regions and industries. The tax would start relatively low and then, unless the outlook changes for better or worse, rise steadily over time to reflect the increasing prospective damages from global warming.

Many considerations enter the balance in weighing prices and quantities. One advantage of price-type approaches is that they can more easily and flexibly integrate economic costs and benefits of emissions reductions, whereas the approach in the Kyoto Protocol has no discernible connection with ultimate environmental or economic goals. This advantage is emphatically reinforced by the large uncertainties and the evolving scientific knowledge in this area. Emissions taxes are more efficient in the face of massive uncertainties because of the relative linearity of the benefits compared with the costs. A related point is that quantitative limits will produce high volatility in the market price of carbon under an emissions-targeting approach. In addition, a tax approach can capture the revenues more easily than quantitative approaches, and may add less to the distortion caused by existing taxes. The tax approach also provides less opportunity for corruption and financial finagling than quantitative limits, because it creates no artificial scarcities to encourage rent-seeking behavior.

However, we must be realistic about the shortcomings of the price-based approach. It is unfamiliar ground in international environmental agreements. Tax is almost a four-letter word. Many people distrust price approaches in general; they are of special concern for global warming because they do not impose explicit limitations on the growth in emissions or the concentrations of GHGs. We might fear that the international community could fiddle with tax rates and definitions and measurement issues and coverage while the planet burns. These are real concerns and will require time and patience to address and overcome.

The coming years will undoubtedly witness intensive negotiations on global warming as the planet warms, the oceans rise, and new ecological and economic impacts are discovered, especially if threats of abrupt or catastrophic impacts become more likely. A dilemma will arise particularly if, as has been suggested above, the quantitative approach under the Kyoto Protocol proves ineffective and inefficient. As policy makers search for more effective and efficient ways to slow dangerous climatic change, they should consider the possibility that price-type approaches like harmonized taxes on carbon are powerful tools for coordinating policies and slowing global warming.

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