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Market-based Policy Options to Control U.S. Greenhouse Gas Emissions

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Growing concentrations of greenhouse gases raise the specter of large-scale climate change and global warming over the next hundred years. Atmospheric concentrations of carbon dioxide have risen from a preindustrial level of 280 parts per million to the current level of over 380 parts per million. Because greenhouse gases persist in the atmosphere for many hundreds of years, the current levels of emissions will have a significant effect on atmospheric concentrations for centuries to come. Scientists are sounding an increasingly urgent call for action to reduce emissions. For background on the science of climate change and the consequences of inaction see, for example, the Intergovernmental Panel on Climate Change (2007) and Stern (2007).

Carbon dioxide is by far the dominant greenhouse gas. The other major greenhouse gases are methane, nitrous oxides (NO_x), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. These gases can be converted into a common unit by the use of "global warming potentials," which provide a multiple for the extent to which emissions of other gases affect climate over a 100-year period relative to CO_2. These conversion factors range widely across greenhouse gases. For example, based on the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), methane's "global warming potential" is 21 while sulfur hexaflouride's is 23,900. A global warming potential of 21 means that one ton of methane has the same global warming impact over 100 years as does 21 tons of carbon dioxide emissions. With nearly 95 percent of carbon dioxide emissions generated by fossil fuel combustion, the major focus of efforts to reduce

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greenhouse gas emissions has been on energy use. Table 1 shows U.S. emissions of greenhouse gases by sector in 2006.

Historically, the United States has tended to use "command and control" regulatory approaches to control pollutants. This approach includes requirements to use best available technology or other specific technology mandates. The most significant existing regulations for reduction of carbon emissions are probably the Corporate Average Fuel Efficiency (CAFE) standards, originally enacted in 1978, which mandate minimum fleet mileage standards for motor vehicles sold in the United States. After being tightened in 2007, CAFE mandates a fleet efficiency of 35 miles per gallon by the year 2020 for cars and light trucks. (For a fuller discussion of CAFE standards, the interested reader might start with Portney, Parry, Gruenspecht, and Harrington in the Fall 2003 issue of this journal.)[1]

Other programs to reduce greenhouse gas emissions have attempted to promote alternative technologies. An example of technology-promoting rules, only enacted at the state level so far, are "renewable portfolio standards" that set a target that some share of electricity be produced by renewable sources. Such requirements are similar to production and investment tax credits for renewable energy, as I analyze in Metcalf (2007a), in providing incentives to particular technologies rather than a general incentive to reduce emissions.

All of these regulatory approaches to reducing carbon emissions raise issues of sectoral inefficiency. For example, fuel economy standards force the automotive sector to bear a disproportionate share of the cost of reducing greenhouse gas emissions, when most studies suggest that the cost of reducing greenhouse gas emissions in the transport sector is quite high compared with other sectors of the economy.

But perhaps the most practical concern with any of the current regulatory approaches is that they are not reducing greenhouse gas emissions. U.S. greenhouse gas emissions have risen by nearly 15 percent since 1990. Emissions of energy-related carbon dioxide are projected to rise by a further 16 percent between 2006 and 2030 (U.S. Energy Information Administration, 2008). If the United States is to reduce its emissions of greenhouse gases, it will need to take far more dramatic steps.

For economists, the obvious choice is to move toward market-based environmental mechanisms that put a price on greenhouse gas emissions. The two main approaches are a carbon tax and a cap-and-trade system of marketable permits for emissions. These market-based approaches are superior to regulatory approaches in a number of dimensions. They ensure that all polluters, regardless of industrial sector, face the same marginal cost of abatement—a necessary condition for efficiency. They provide the right incentive to shift the larger pollution reductions

[1] A potentially significant regulatory approach at the state level is California's low-carbon fuel standard put in place by Governor Arnold Schwarzenegger in 2007. Holland, Knittel, and Hughes (2009) note that such a policy could in fact lead to an increase in emissions, and that even if the standard does reduce emissions, a low-carbon fuel standard is a particularly costly approach.

Table 1
U.S. Greenhouse Gas Emissions by Sector in 2006

Sector	*Emissions*	*Share*
Electricity	2,378	34%
Transportation	1,970	28%
Industry	1,372	19%
Agriculture	534	8%
Commercial	395	6%
Residential	345	5%
Total	**7,054**	

Source: U.S. Environmental Protection Agency (2008), Table ES-2.
Note: Emissions are measured in millions of metric tons of CO_2e (carbon dioxide equivalent). The total in the bottom row includes emissions from U.S. territories not included in the other row entries.

from firms or sectors with high marginal abatement costs to those with low marginal abatement costs. Pricing pollution also encourages innovation, given the potential for reducing pollution at lower cost with new technology, and thus reduces the price that needs to be paid for emissions of greenhouse gases.

This paper begins by looking at some design issues that confront any policy for putting a price on greenhouse gases. I introduce the specific policy instruments of 1) taxing greenhouse gas emissions and 2) a cap-and-trade program. I then offer some comparisons of the two options along various dimensions: How well can they deal with uncertainty in costs of abating pollution? What are their implications for industry rents and government revenue? Do they differ in ease of administration? How would they be linked to existing programs, including those in other countries? I conclude with some observations on the likely directions of climate change policy in the United States. A note on terminology: Since carbon makes up the vast bulk of greenhouse gas emissions, it is standard practice to refer to the price of carbon (permit price or tax rate) rather than the price of greenhouse gas emissions. Other greenhouse gases can be denominated in units of carbon so nothing is lost in this terminology. Despite the use of this terminology, a carbon tax or cap-and-trade system can (and should) extend to greenhouse gases beyond carbon.

Design Issues

Any policy instrument for putting a price on greenhouse gas emission—whether a tax or a cap-and-trade system—faces several central design issues.

Upstream or Downstream?

The first question concerns the point at which the policy should be administered. For fossil fuels, for example, a carbon pricing policy can be imposed where the fuel is burned or at some earlier stage of production. Unlike the case of water pollution, where changes in production processes can result in less pollution, changes in processing and different uses of carbon fuels do not affect total emissions of carbon. Emissions per ton of lignite coal, for example, are essentially constant, and so the carbon price on this coal could be applied at the power plant where the coal is burned, on the railroad or pipeline that transports the coal, or on the producer of the coal (either the firm that mines it or the company that imports it).

A carbon price imposed on fossil fuel users is termed a *downstream* system while a price imposed on producers is an *upstream* system. Implementing the price upstream reduces the number of firms that must be included in the pricing system. In contrast, a comprehensive downstream system would include each factory using fossil fuels, gas stations where gasoline is sold to drivers, and oil and gas distributers. Cambridge Energy Research Associates (2006) estimates that millions of point sources would fall under an inclusive downstream carbon pricing system.

What Greenhouse Gases Should Be Covered?

Putting a price on fossil fuels used for energy production covers 80 percent of greenhouse gas emissions, as shown in Table 2. Some non-fossil fuel emissions would be relatively easy to bring into a carbon pricing system. For example, carbon pricing could be applied fairly easily to nonenergy carbon emissions from iron, steel, and cement production. In the case of cement production, for example, carbon emissions result from the production of "clinker," an intermediate product, which is a combination of lime and silica-containing materials. The quantity of CO_2 released during production is directly proportional to the lime content of the clinker and so carbon pricing could be imposed on clinker production. There are 118 cement plants in the United States owned by 39 companies. These large, stationary sources of emissions would be relatively easy to bring into a carbon pricing system. Concentrated production or use of hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride also suggest it should be relatively straightforward to address these emissions in a carbon pricing policy.

In contrast, releases of nitrous oxides through agricultural soil management are more difficult to incorporate into a carbon pricing scheme, because actual emissions vary according to factors like the granularity of the soil and cannot be measured directly. Roughly 20 percent of nitrous oxide emissions arise from the use of artificial fertilizers, but a policy that raises the price of nitrogen-based fertilizers could easily encourage practices that raise other greenhouse gas emissions. Higher fertilizer prices, for example, create incentives to substitute toward manure which raises the demand for livestock and, therefore, possibly increase emissions from livestock.

In Metcalf and Weisbach (2008), my coauthor and I discuss other significant emissions sources and conclude that roughly 90 percent of U.S. greenhouse gas

Table 2
Major Greenhouse Gas Sources in 2006

Rank	*Source*	*Gas*	*MMT CO_2e*	*Share*	*Cumulative Share*
1	Fossil fuels	CO_2	5,637.0	79.9%	79.9%
2	Agricultural soil management	N_2O	265.0	3.8%	83.7%
3	Nonenergy use of fuels	CO_2	138.0	2.0%	85.6%
4	Landfills	Methane	132.0	1.9%	87.5%
5	Enteric fermentation	Methane	126.2	1.8%	89.3%
6	Ozone depleting substance substitutes	HFC	110.4	1.6%	90.8%
7	Natural gas systems (methane)	Methane	102.4	1.5%	92.3%
8	Coal mining	Methane	58.5	0.8%	93.1%
9	Iron and steel production	CO_2	49.1	0.7%	93.8%
10	Cement manufacturing	CO_2	45.7	0.6%	94.5%
11	Manure management	Methane	41.4	0.6%	95.1%

Source: Metcalf and Weisbach (2008) based on data from U. S. Environmental Protection Agency (2008).
Note: Emissions are measured in millions of metric tons (MMT) of CO_2e (carbon dioxide equivalent). Enteric fermentation takes place in the digestive systems of ruminant animals such as cows.

emissions could be brought into a carbon tax base (or a cap-and-trade system) at relatively low cost. Paltsev et al. (2007) provide an analysis of carbon pricing that suggests significant efficiency gains arise from including non-CO_2 gases in the policy scheme. This reflects the relatively lower cost of reducing non-CO_2 emissions in the short run.

Other Issues: Carbon Capture, Price, and Policy Integration

Any policy to put a price on greenhouse gas emissions needs to ensure that the price does not apply to emissions that are captured and stored permanently. This includes fossil fuels used as feedstocks in manufacturing activities, in which the carbon is permanently stored in the product. It also applies to fuels that are burned in plants where carbon capture and storage is utilized—technologies that remove carbon from the exhaust streams and store it underground, either locally or after transportation to a storage site, for many centuries.

Sequestration is especially important for coal. The United States has one-third of the world's reserves of coal (BP, 2008). Nearly all the coal consumed in the United States is used to produce electricity, accounting for over half of electricity production domestically. China also has large coal reserves (13 percent of the world total). It is unlikely that either country will willingly set aside these inexpensive energy resources despite concerns about the climate. This fact gives greater urgency to the need for technological and regulatory advances in carbon sequestration.

Proposals for carbon pricing that have been floated in the United States have prices that start in the neighborhood of \$15 to \$20 per ton of CO_2, or its equivalent from other gases, and then rise over time. Ideally, the price would be set equal to the marginal damages of emissions, but no consensus exists on an estimate of the marginal damages and hence the optimal carbon price (as Tol discusses in this issue). Price trajectories in most federal proposals for carbon taxes or cap and trade are linked directly or indirectly to a desired reduction in aggregate emissions over the first half of this century.

Finally an important design consideration will be how to integrate U.S. policy with current or proposed policies in other countries and at the state or regional level in the United States. I discuss this theme below.

A Tax on Greenhouse Gas Emissions

Since carbon makes up the vast bulk of greenhouse gas emissions, a tax on greenhouse gas emissions is generally referred to as a carbon tax. An upstream carbon tax applied to fossil fuels, along with the carbon equivalent in certain other greenhouse gases, is relatively straightforward to administer, because nearly all of the firms that would be subject to the tax already pay taxes on the products that would be subject to the carbon tax.

The tax would need to be combined with a crediting mechanism to provide a rebate of taxes paid on emissions that are sequestered at a downstream location. Electric utilities that burn coal in an advanced boiler with carbon capture and storage technology, for example, should be allowed a (perhaps tradable) tax credit for sequestered carbon. Credits for certain land-use activities, including forestry sequestration, could also be considered for credit eligibility. In this way, sectors not covered by the carbon tax could receive payments for approved carbon-reducing activities.

We have some experience with the use of carbon taxes in different parts of the world; indeed, because a carbon tax is in large measure a tax on energy use, we can also draw on information from the extensive use of energy taxes throughout the world. Finland passed the first carbon tax in 1990, followed soon after by Sweden, Denmark, the Netherlands, and Norway. Finland's tax rate is currently €20 (equivalent to $26) per ton of CO_2 and applies to liquid fuels and coal. A reduced rate is applied to natural gas, and electricity is not subject to the tax. Finland's carbon tax is a surtax on existing energy taxes and was increased 13 percent at the beginning of 2008. The tax raises roughly €500 million annually.

Bruvolle and Larsen (2004) estimate that Norway's carbon tax reduced greenhouse gas emissions (carbon dioxide, methane, and nitrous oxides) by 2 percent in 1999 relative to what emissions would have been in the absence of the tax. To put this in perspective, emissions of these gases grew by nearly 16 percent during the decade despite the tax being put in place in 1991. While the maximum carbon tax rate in Norway was $51 per ton of carbon dioxide equivalent, or CO_2e, various sectors were taxed at lower rates or exempted from the tax altogether. Bruvolle and Larsen estimate that 64 percent of emissions were subject to the tax and that the tax rate averaged across all emissions was $21 per ton. The authors estimate that a comprehensive carbon tax set at $21 per ton would have reduced emissions in Norway by approximately 14 percent.

The story in Sweden is similar. It passed a carbon tax in 1991 with an initial rate of SKr250 per ton CO_2 (roughly $10 per ton of CO_2). Sweden's tax is indexed for inflation and was recently raised by SKr60 per ton of CO_2. However, Sweden's tax has only limited effect, because it is not applied to fuels used in electricity production and the rate is cut in half for fuels used by industry. Also, deeper reductions are allowed to energy-intensive industries (Johansson, 2000). The exclusion of the electricity sector in the case of Sweden is not nearly as significant as it might appear because Sweden generates most of its electricity from hydro and nuclear power. The United States, in contrast, generates over half of its electricity from coal. The carbon tax raised SKr 24.7 billion in 2006, roughly 1.75 percent of general government tax collections (including Social Security contributions) (Swedish Tax Agency, 2008, Table 17). Norway is similar to Sweden in that its carbon tax raises a significant amount of revenue (roughly 1.7 percent of total tax revenues), is differentiated across fuel types, and exempts significant sectors from taxation.

The province of Quebec in Canada put in place a carbon tax designed to raise roughly $200 million Canadian in 2008 (Tomesco, 2007). This modest tax amounts to 0.8 cents per liter of gasoline (3 cents per gallon). The tax is levied on fuel distributors and applies to gasoline, diesel, natural gas, and electricity from fossil fuels. As such, it is a limited tax on greenhouse gas emissions. In 2008, the province of British Columbia enacted a broad-based carbon tax with an initial rate of $10 (Canadian) per ton of CO_2, to be raised by $5 per ton per year for the following four years (Ministry of Finance, Province of British Columbia, 2008). The tax applies to virtually all fossil fuels, with revenues earmarked for tax reductions as a revenue neutral reform. The tax went into effect in July 2008. It is too soon to evaluate the effects of either of these taxes.

Stern (2007) identifies three defects in the way that most countries have implemented carbon taxes to date. First, numerous exemptions have been provided to industry, which add significant complexity to the tax and weaken the incentives to reduce carbon emissions. Second, tax rates across different fuels typically do not reflect the carbon emissions arising from their use. Third, countries imposing a carbon tax have not attempted to harmonize their tax rates. This pattern is particularly striking in the Scandinavian countries that all implemented carbon taxes in the early 1990s. The provincial tax in British Columbia has taken a more comprehensive approach, though a tax at a sub-national level in isolation has more symbolic than substantive value.

Clearly, the early steps toward a carbon tax have been tentative and limited in nature. Most carbon taxes were not comprehensive in coverage. Despite this, some countries have collected relatively significant amounts of revenue from the tax—Sweden and Norway in particular.

Finally, one might argue that the United States and many other countries have an implicit carbon tax in place in the form of taxes on motor vehicle fuels. The average federal and state tax rate on gasoline in the United States equals 45 cents per gallon (American Petroleum Institute, 2009). In contrast, a number of European countries including Germany, the Netherlands, and the United Kingdom face tax rates on gasoline above \$3.00 per gallon (Metcalf, 2009). The average gas tax in the United States is equivalent to a carbon tax rate of \$50 per ton of CO_2 while a European tax rate of \$3.00 is equivalent to a carbon tax rate of about \$340 per ton of CO_2. Driving has a number of other externalities than global climate change from carbon emissions (congestion, tailpipe pollution, health problems, and others) that can be addressed with some form of a gasoline tax. Parry and Small (2005) consider the range of externalities associated with driving and conclude that the U.S. tax rate on gasoline is roughly half its optimal level. The tax in the United Kingdom, in contrast, is roughly twice its optimal level.

High gas taxes in Europe have contributed to reductions in driving and the production of more fuel-efficient vehicles. But a gas tax is not a substitute for a carbon tax. First, the tax covers at most one-third of U.S. carbon dioxide emissions because it excludes from coverage industrial oil use as well as coal and natural gas. Second, taxes on gasoline were put in place for a variety of reasons, ranging from concerns over driving-related externalities to a desire to fund highway construction. A carbon tax would address an externality not accounted for in the political calculations that entered into the existing gas tax.

Cap-and-Trade Program

In its simplest form, a cap-and-trade program sets an aggregate limit on emissions and creates permits for this amount. The government can issue the permits for free to regulated firms or other entities (for example, like state governments), auction the permits, or use some combination of free distribution and auctions. Regulated firms must surrender permits equal in value to the emissions for which their activities are responsible. The permits may be bought and sold so that firms with high costs of emissions abatement may purchase permits from firms with low abatement costs. With a well-functioning permit trading market, the permit price reflects the opportunity cost at the margin of a firm's emissions. Equating marginal costs across all firms emitting greenhouse gases is a necessary condition for efficiency. While a carbon tax fixes the price of emissions and leaves the market to determine the equilibrium quantity, the cap-and-trade program fixes the quantity of emissions and leaves the market to determine the price.

We now have some experience with cap-and-trade programs that can inform a decision on how best to design a program to control greenhouse gas emissions; this subject is usefully discussed in Stavins (2003). The first significant use of cap and trade was the sulfur dioxide (SO_2) trading program for electric utilities established under the Clean Air Act Amendments of 1990. The trading program was designed to reduce SO_2 emissions by ten million tons and nitrogen oxide emissions by two million tons from 1980 levels. Phase I of the program from 1995 to 2000 covered 263 generating units in 110 plants, most of which were large coal-fired facilities east of the Mississippi River. Phase II beginning in 2000 expanded the coverage of the program to most electric generating facilities with capacity of 25 MW or greater and tightened the caps further. Permit trading appears to have reduced the cost of achieving lower SO_2 emissions on the order of 50 percent. Ellerman, Joskow, Schmalensee, Montero, and Bailey (2000) present an analysis of cost savings; also see Schmalensee, Joskow, Ellerman, Montero, and Bailey (1998) and Stavins (1998).

Other trading programs include the Regional Clean Air Incentives Market (RECLAIM) program to reduce nitrogen oxide and sulfur dioxide emissions in the Los Angeles region that began in 1994. A regional trading system in nitrogen oxides for the northeastern states began in 1999—the Northeast Ozone Transport Region—allows trading for covered sources. However, these U.S.-based programs are all relatively small-scale in comparison to the projected size of a national cap-and-trade system for carbon emissions.

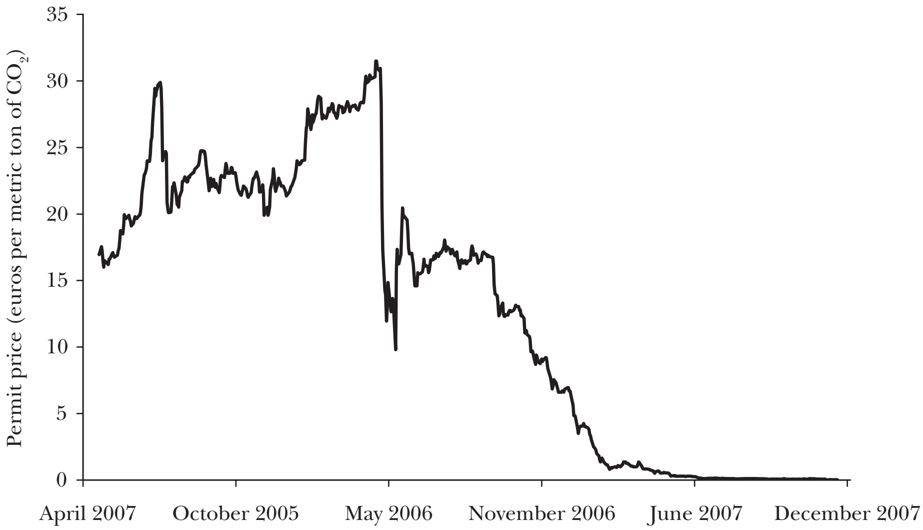
On January 1, 2005, 25 countries in Europe embarked on a major policy experiment in the use of market-based instruments to control greenhouse gas emissions. The European Union's Emissions Trading Scheme is a cap-and-trade program in which country-by-country caps on carbon emissions were set for energy-intensive industries and the utility sector, and permits for emissions were issued. The program does not include the transportation sector.

Carbon permits can be traded within and across countries in the European Union. Ellerman, Buchner, and Carraro (2007) describe the design and allocation process in the first phase of the program from 2005 to 2007, which was designed as a trial run to work out the kinks in large-scale trading. The experience in this period illustrates both the strengths and challenges of a carbon pricing system.

First, prices exhibited considerable volatility. Permit prices fell sharply in April 2006 on the release of information indicating that the permit allocations had been overly generous. The December 2008 futures price fell from a peak of €32.25 on April 19, 2006, to €22.15 on April 26, 2006, and to €17.80 on May 12, 2006. Prices rebounded briefly but drifted downward for much of the rest of 2006. Volatility in the Phase I permits was even higher, as shown in Figure 1. These permit prices fell from €31.50 on April 19 to €9.80 on May 15, before rebounding briefly.

Second, the experience in Phase I of the EU Emissions Trading Scheme illustrates the importance of allowing trading across time periods. Permits from Phase I were not allowed to be used in Phase II of the program—running from 2008 to 2012. The inability to save permits for future use, along with the overallocation of permits in the first phase, drove the permit price essentially to zero by the middle of 2007. Allowing permits to be saved for use in later years is known as "banking" and contributes considerably to the efficiency of a trading program. Given the long-lived nature of most major greenhouse gases, it is relatively immaterial whether a ton of carbon dioxide is released into the atmosphere today or in

Figure 1
Permit Price for Carbon Emissions, Phase 1 of the European Union's Emissions Trading Scheme



Source: European Climate Exchange (2008).

15 years.[2] Banking allows firms to make inexpensive reductions now in excess of their required reductions and so smooth their adjustment costs as permit prices rise in the future with tightening restrictions on emissions. Banking also drives up the price of current permits, thereby sending a signal through the market that long-run capital investments to reduce emissions will be profitable.

Third, Phase I illustrated the lead-time required to implement a cap-and-trade program. The Kyoto Protocol was signed in 1997 and the trading system went into effect in 2005. During this time, a system of national allocations was established and measuring, monitoring, and verification systems put in place. Once all this was up and running, permit price volatility declined over time as markets thickened. For example, average volume rose from a half million contracts in 2005 to nearly seven million contracts in the first three quarters of 2008.

One concern has been the European practice of giving the emissions permits to firms at no cost. An alternative would be to auction them. Proposals for cap-and-trade programs in the United States have increasingly called for auctioning a significant share of the permits with proceeds used for a variety of initiatives including green spending and tax reductions. I discuss this point further below.

[2] The majority of carbon emissions released today will be removed from the atmosphere within 100 years, but roughly one-fifth will persist for many centuries (Intergovernmental Panel on Climate Change, 2007).

The first instance of a carbon cap-and-trade system in which all of the permits will be auctioned has just gotten underway in the U.S. Northeast with the Regional Greenhouse Gas Initiative (RGGI). Ten states in the Northeast and Middle Atlantic regions have committed to capping carbon emissions from electric power plants 25 MW or greater in size at 2009 levels between 2009 and 2014 and then reducing emissions by 2.5 percent per year for the next four years. Proceeds from the auctions will fund energy efficiency and renewable investments in the region. Covered facilities under RGGI account for roughly one-quarter of greenhouse gas emissions in the region.

The first RGGI auction took place in September 2008 and the market clearing price for emissions was $3.07 per ton of carbon dioxide. Given the slowdown in the region's economy since the cap was established, widespread concern exists that the cap may not bind (Daley, 2008). While it is possible that the reason the cap may not bind at a high price is because utilities are undertaking aggressive efforts to reduce emissions, it is more likely that the cap was initially set at a relatively high level. This raises a general point that cap-and-trade programs are only effective at reducing emissions significantly if the caps are set at levels substantially below the business-as-usual emission levels.

Cap-and-trade systems have appealed to policymakers in the United States, both because they appear to offer greater certainty about the quantity of emissions and also because they do not explicitly place a price on emissions. However—as noted above—setting a cap is not the same as reducing emissions. Also, cap and trade is an indirect pricing instrument raising the possibility of large price swings for the permits. The permit price volatility experienced in the European cap-and-trade program is not unique. Permit prices for the California Regional Clean Air Incentives Market (RECLAIM) rose abruptly from under $5,000 per ton of nitrous oxides (NO_x) to nearly $45,000 per ton in the summer of 2000. Permit prices in EPA's Acid Rain Program rose to nearly $1,600 per ton SO_2 in late 2005 from a price of roughly $900 at the beginning of the year. NO_x prices in the Northeast states' Ozone Transport Commission jumped to nearly $8,000 per ton in early 1999 before falling back to more typical levels between $1,000 and $2,000 per ton. Unexpectedly high permit prices erode political support for the program and led in the RECLAIM market to a relaxation of the permit cap in response to the high prices.

Concerns with the potential volatility of carbon prices have led a number of analysts to propose hybrid systems combining elements of price and quantity systems (for example, Pizer, 2002; Stavins, 2007). The simplest hybrid is the "safety valve" approach in which a cap-and-trade system is implemented with a provision allowing firms to purchase an unlimited number of permits at a set price—thus setting a ceiling on the price of permits. A cap-and-trade system which reaches its binding safety valve price level in effect becomes a carbon tax. Even in the absence of an explicit safety valve, we should not assume that the caps in a cap-and-trade law are fixed. After all, Congress serves as the ultimate safety valve if it finds carbon prices rise to unacceptable levels.

Variations have been proposed on the basic safety valve approach. For example, Murray, Newell, and Pizer (2008) propose a variant on a safety valve system by limiting the number of allowances that the government could sell. A fixed allowance reserve that caps the number of allowances the government could sell balances the desire to manage costs under a permit system with a commitment to limiting emissions. Burtraw and Palmer (2006) note that a safety valve lowers the expected permit price and can discourage investment in new technologies to reduce emissions. They recommend combining a safety valve with a price *floor* to maintain the same expected permit price as would occur in the absence of a safety valve. The risk of low permit prices in the future will tend to reduce returns to investments in innovative technologies to reduce carbon emissions.

Allowing banking and borrowing of emission permits can reduce short-term volatility. Recall the experience in Europe with the transition from Phase I to Phase II of its permit system. If firms had been allowed to bank permits between the two phases, permit prices would not have gone to zero in Phase I and prices in Phase II would have been slightly lower at the beginning of the second phase.

Assessing the Options

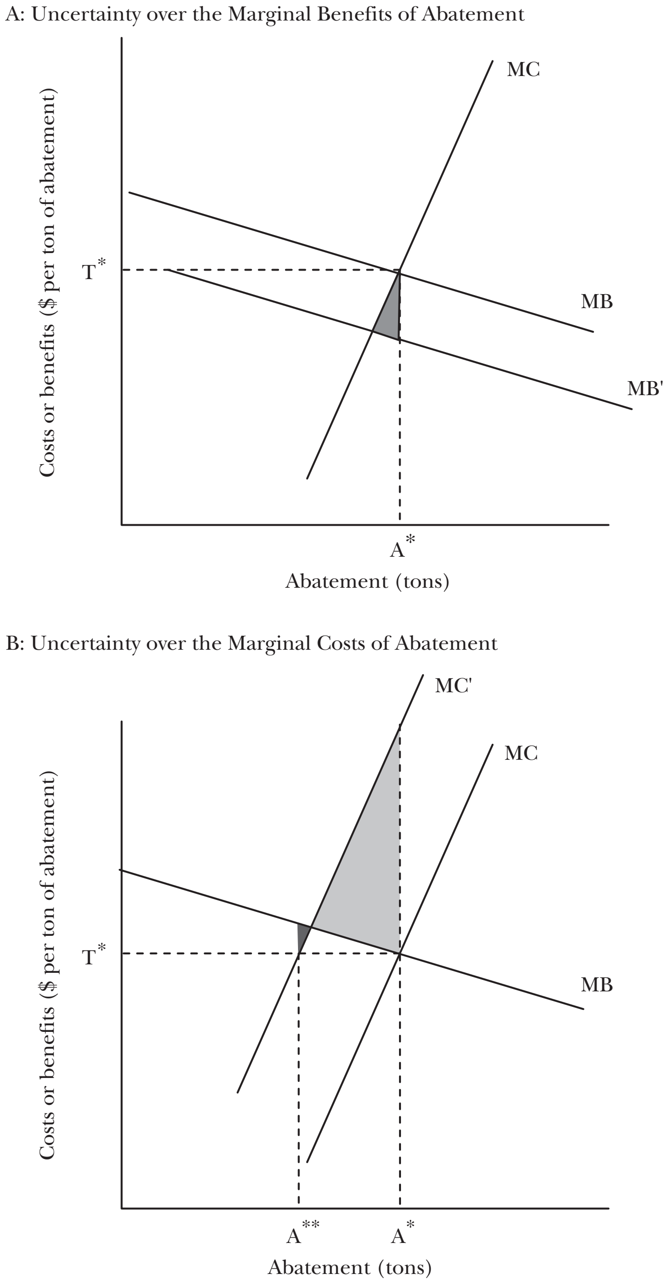
Nearly all economists agree that upstream implementation of a carbon pricing policy is preferable to a regulatory approach and that all fossil fuels should be included in such a policy. How many of the additional greenhouse gases should be included in the system or how to bring them in may differ across proposals depending on views about how feasible it is to measure and incorporate them. However, carbon taxes and cap-and-trade systems do differ along a number of key dimensions.

Emissions with Uncertainty in Abatement Costs

If marginal costs of abating carbon are known with certainty, the same emissions outcome can be achieved with either a price mechanism like a carbon tax or a quantity mechanism like a cap-and-trade system. However, if the marginal abatement cost curve is uncertain, then the two approaches are no longer equivalent. This follows from an application of Weitzman's (1974) framework of optimal instrument choice under uncertainty.

Figure 2 illustrates the idea behind Weitzman's (1974) model. The horizontal axis measures reductions in emissions of some pollutant (A). The downward sloping curve is the marginal benefits (MB) curve for reducing emissions of this pollutant. This line reflects the social benefits of pollution reduction. From the polluter's point of view, the marginal benefit of abatement is zero. The upward sloping curve measures the marginal cost of abatement (MC). The vertical axis measures marginal costs and benefits in dollars per ton of abatement. In the absence of policy, the firm would undertake no abatement activities. In Figure 2A, we can increase abatement activity either by setting a tax on emissions or by capping

Figure 2
Uncertainty over the Marginal Benefits or the Marginal Costs of Abatement



emissions at some limit. If a tax is levied, then the firm's private marginal benefit of emissions abatement equals the tax rate (T*). If a cap on emissions is set, then the firm is required to engage in a certain amount of abatement activity (A*). If the tax is set assuming marginal cost and benefit curves MC and MB respectively, abatement amounts of A* will occur. Conversely, if abatement of A* is required, then the shadow price of the cap will equal T*.

Now imagine that the tax or cap on emissions is set assuming the marginal benefit curve MB but the actual marginal benefit curve is MB′. The firm will continue to abate to A* whether it faces a tax or an emissions cap. The cap requires A* of abatement and the tax leads the firm to choose A* in abatement to maximize profits. The two policies will result in equally inefficient outcomes with deadweight loss given by the shaded triangle in the figure. The first observation from Weitzman's model is that uncertainty in the marginal benefit curve will not affect the optimal choice between taxes and pollution caps.

Next consider uncertainty over the marginal abatement cost curve, illustrated in Figure 2B. T* and A* are set assuming marginal benefits and costs of MB and MC. If MC′ is the actual marginal abatement cost curve then the tax will lead to A** of abatement with deadweight loss given by the small dark triangle whereas the cap requires A* of abatement leading to deadweight loss represented by the larger lightly shaded triangle. As drawn, the pollution cap has greater deadweight loss than does the tax. As Weitzman demonstrates, this difference is driven by the relative slopes of the marginal benefit and cost curves. If the marginal benefit curve is flatter than the marginal cost curve, then the tax will lead to lower expected deadweight loss than the cap. The intuition is straightforward: We would like the private cost of emissions (either the tax or shadow price of the cap) to reflect the marginal damages of pollution (or equivalently the marginal benefits of abatement). With a relatively flat marginal benefit MB curve, the tax is more likely to be "close" to marginal damages than will the shadow price of a cap. Conversely, if the MB curve is very steep, this suggests that the pollutant has some threshold effect that drives damages up sharply if abatement is set too low. In that case, society is better off with a cap to ensure that a sufficient level of abatement occurs.

Greenhouse gases are a pollutant where a stock builds up over time, and so the analysis is a bit more complicated, but the intuition carries over to a large extent. With a stock pollutant that persists in the atmosphere for a very long time, marginal damages from emissions in any given year are essentially constant. A flat MB curve favors the tax approach. This insight is borne out by a number of analyses that have found that taxes dominate cap-and-trade systems for a broad range of parameter values consistent with scientific understanding of the global warming problem (for example, Hoel and Karp, 2002; Karp and Zhang, 2005; Newell and Pizer, 2003).

The analyses described above assume a policy choice is made at one point in time and then is not altered as new information is received. This is a limitation of the Weitzman model as Congress is likely to review allowance targets under a cap-and-trade system and tax rates under a carbon tax as new information becomes available. With frequent updating, the efficiency differences are reduced and—in the limit with continual updating—the two instruments once again have identical efficiency consequences.[3]

Rents and Revenue

A U.S. carbon pricing policy has the potential to raise significant revenue. The U.S. Department of State (2007) projects greenhouse gas emissions of 8,115 million metric tons in 2012. Energy-related carbon dioxide emissions are projected under the business-as-usual scenario to be 6,318 tons. Assuming a modest reduction in emissions from a carbon pricing policy—either a tax or cap-and-trade system with auctioned permits applied just to energy-related CO_2 emissions—such a program could raise roughly $90 billion annually for a carbon price of $15 per ton.

Of course, a cap-and-trade system only raises revenue if the permits are sold by the government. Historically, permits in other U.S. cap-and-trade programs have been given away to industry as part of a process of obtaining political support for the system. The EU Emissions Trading Scheme also has given the permits away for free. To be fair, prior U.S. cap-and-trade programs were an order of magnitude smaller than any potential carbon cap-and-trade program. Thus, given the revenues involved, auctioning permits in those programs was simply not that important. As noted above, the RGGI program in the U.S. Northeast has committed to 100 percent auctioning of permits.

In addition to the loss of substantial revenue, freely allocated permits may undermine the key goal of discouraging the consumption of carbon-intensive energy. Although retail competition for electricity exists in many states (primarily in the Northeast), a large proportion of electricity consumers still operate in markets subject to state-level regulation (Joskow, 2006). It is unclear if regulators will allow regulated utilities to pass through the cost of carbon emissions permits in the form of higher electricity prices for customers if the permits are given without charge to the utilities. In that case, carbon emissions permits would have no effect in reducing electricity demand—although they would still encourage utilities to find alternative sources or fuels for electricity that use less carbon.

In deregulated markets, utilities that are freely given permits will likely raise the price of electricity because the marginal cost of production would then include the opportunity cost of giving up permits they could have sold. This increase in the price without any commensurate increase in the utilities' real costs will generate windfall profits. This pattern unfolded during the first allocation period of the

[3] The inefficiency described above is distinct from the inefficiency that arises from distortionary taxes. Set aside the uncertainty described above for the moment. In the absence of other distortions in the economy, a tax set at the marginal damages of pollution (or a cap-and-trade system with shadow price of emissions equal to marginal damages) would be efficient. With pre-existing distortions, however, a carbon tax leads to lower pollution damages but also generates its own deadweight loss (this is known as the "tax interaction effect"). The important point for instrument choice is that a carbon tax and a cap-and-trade system that lead to the same price on emissions have equivalent distortionary impacts through the tax interaction effect. The argument that taxes are distortionary does not favor cap-and-trade systems. They are equally distortionary on this dimension.

European Union's Emissions Trading Scheme and led to controversy and discussion of re-regulation. Such windfall profits are simply the realization of the value of freely given permits to the electric utilities and reflect the fact that complete grandfathering overcompensates energy industries for losses they incur through the imposition of carbon pricing. In their analysis of a possible U.S. cap-and-trade system, Bovenberg and Goulder (2001) find that grandfathering more than 4 percent of permits in the coal industry and 15 percent in the oil and gas industry overcompensate these industries for their losses. Utilities actually lose relatively little from permit costs because these costs are largely passed forward to final consumers in the form of higher energy prices.

The issue of revenue from carbon pricing also raises the question of distributional effects. Table 3 presents results from a distributional analysis of carbon pricing on U.S. households using data from the 2003 Consumer Expenditure Survey. Most analyses of energy taxes suggest that they are shifted forward to consumers in the form of higher energy prices. I measure the effect on household purchases of a $15 per ton carbon price taking into account the direct effect (higher cost of energy purchases) as well as the indirect effect (higher cost of goods and services due to increase in energy costs of production). I describe this methodology in detail in Metcalf (1999) and have used it (Metcalf, 2007b) to evaluate carbon tax reforms. Dinan and Rogers (2002) also use this methodology to evaluate permit allocation under cap-and-trade programs in the United States.

The first column of Table 3 illustrates that carbon pricing by itself is regressive. Low-income households spend over 3 percent of their income in higher costs for goods and services for the carbon price. The share of income going to pay the carbon price falls to just under 1 percent for the highest-income groups. I also report results for two different ways in which carbon revenues could be returned to households. First, I consider a reform detailed in Metcalf (2007b) where an environmental earned income tax credit is provided to workers capped at a level that makes the reform revenue-neutral. For a $15 per ton carbon price in 2003, the cap is $560 per worker. This reform, reported in column 2, eliminates most of the regressivity of the carbon price, and modest variations in this reform can make the net transfer distributionally neutral or progressive as desired. In contrast, a return of revenue to energy producers (or equivalently free distribution of permits to energy producers) leads to a distinctly regressive outcome (column 3). Clearly, how carbon revenues are used has significant distributional implications.

The analysis in the first three columns of Table 3 takes an annual income incidence approach. A large body of research shows that the distributional impact of taxes can look very different if we use a lifetime incidence approach (for example, Davies, St-Hilaire, and Whalley, 1984; Poterba, 1989, 1991; and others). Drawing on work described in Hassett, Mathur, and Metcalf (2009), the last column of Table 3 shows that the regressivity of carbon pricing is blunted significantly if one uses a lifetime measure of income in the incidence analysis. The annual income and lifetime income approaches are two ends of a spectrum. People clearly take future income into account when making consumption decisions today; on the

Table 3
Income Distribution and Carbon Pricing

	Mean tax change as a percentage of disposable income			
Income group (decile)	*Carbon pricing alone*	*With revenue returned to households*	*With revenue returned to energy producers*	*Carbon pricing: lifetime measure*
1 (lowest)	−3.4	−0.7	−1.8	−1.2
2	−3.1	−1.0	−0.6	−1.2
3	−2.4	−0.2	−0.6	−1.2
4	−2.0	0.1	−0.4	−1.2
5	−1.8	0.1	−0.5	−1.3
6	−1.5	0.3	−0.5	−1.2
7	−1.4	0.2	−0.2	−1.2
8	−1.2	0.2	−0.2	−1.1
9	−1.1	0.0	0.1	−1.0
10 (highest)	−0.8	0.0	0.5	−0.9

Sources: Metcalf (2007b) for annual income measures; Hassett, Mathur, and Metcalf (2009) for the lifetime income measure.
Note: Table 3 presents results from a distributional analysis of carbon pricing on U.S. households using data from the 2003 Consumer Expenditure Survey. I measure the effect on household purchases of a $15 per ton carbon price taking into account the direct effect (higher cost of energy purchases) as well as the indirect effect (higher cost of goods and services due to increase in energy costs of production). See text for details. The lowest decile includes households in the 5th to the 10th percentiles.

other hand, it is unlikely that most people are full lifetime-income optimizers. We can think of the annual and lifetime income incidence measures as bracketing the true distributive effect.

Finally, let me note another distributional concern: that certain sectors are disproportionately affected by a carbon price. This concern is particularly relevant for the coal industry. We should not protect coal from carbon pricing, but we may wish to provide transitional assistance in this industry. The cost should not be that great. The value added by the coal industry (labor compensation, owners' profits, and indirect business taxes) totaled $11 billion in 2005. If the share of labor compensation in coal mining value added is unchanged from 1997, when labor accounted for one-half the value added in coal mining, the maximum potential loss to labor is $6.5 billion annually. This puts an upper limit on the losses to this sector; actual losses will be less, since coal production will not disappear. Moreover, as time goes on, participants in this industry can begin to make adjustments to move into other sectors. Thus, any transitional assistance should be temporary in nature with particular attention paid to those factors that are least able to make a transition to new jobs (for example, older workers).

Administration

How quickly could a carbon pricing system be put in place? A carbon tax would be implemented through the Internal Revenue Service and could piggyback on existing energy taxes. For example, coal producers already pay an excise tax to fund the Black Lung Trust Fund and oil producers pay a tax to fund the Oil Spill Trust Fund. The United States also has precedents for refundable credits for CO_2 sequestration activities in ethanol tax credits in the federal gas tax.

The United States also has a model for running an upstream carbon cap-and-trade program in the SO_2 trading program described earlier, which has been administered by the Environmental Protection Agency. However, the experience from establishing cap-and-trade systems suggests considerable lead-time is required to establish allocations (Congressional Budget Office, 2008).

Linkage with Existing Programs

Any federal carbon pricing scheme would have to be linked to existing programs. Linkage issues arise in three contexts: cap-and-trade programs in other countries; sub-federal cap-and-trade programs; and other carbon policies in other countries. My discussion of these issues draws on Stavins (2007).

Consider first linkage with cap-and-trade programs in other countries. A U.S. cap-and-trade system would need to decide whether permits could be purchased from foreign cap-and-trade programs. If so, would there be limits on the number of permits that could be used? A cap-and-trade bill reported to the floor of the U.S. Senate in 2007 provided for the use of permits from other trading programs up to 5 percent of allowed emissions. Next, the United States would have to decide whether it would demand reciprocity, in which case foreigners could purchase U.S. emissions permits.

Full harmonization across countries has the potential to bring down the costs of achieving domestic caps given the greater flexibility in reducing emissions in a harmonized program. On the other hand, if the price for permits are set as a result of extensive international trading, then no individual country will control the price paid for its own domestic emissions. Moreover, full harmonization has the potential to degrade the quality of domestic permits to the extent that some foreign governments have lax standards for measuring, monitoring, and verifying emission reductions in their countries. U.S. firms could end up buying permits from other countries based on the promise of significant reductions in those countries that are never realized.

Strictly speaking, one cannot link a foreign cap-and-trade system with a domestic carbon tax. But we can connect the two systems by harmonizing the price of carbon in the two systems. A commitment to keep permit prices and tax rates within some range ensures that "leakage"—the movement of economic activity from countries that price carbon to those that don't—remains a second-order issue. A useful component of a global agreement to address greenhouse gas emissions would be an agreement on a price path for carbon emissions, which would still leave the decision on instrument choice to each country.

Next is the question of linkage of a national U.S. cap-and-trade program with U.S. state or regional programs. For example, would electric utilities in the Northeast states subject to RGGI be required to surrender federal as well as RGGI permits for their emissions? Stavins (2007) recommends that the federal program pre-empt state and regional programs to avoid confusion and administrative complexity. Presumably pre-emption would be combined with some mechanism to convert existing permits in the state or regional program into federal permits. Similarly, a federal carbon tax could, though need not, preempt state and regional cap-and-trade programs.

Finally, what to be done about countries that do not have a carbon pricing policy? Concerns about leakage of economic activity have largely focused on the possible loss of jobs to China, India, and other emerging developing countries if the U.S. adopts some form of carbon pricing and these countries don't. However, it should be noted that a large fraction of U.S. energy-intensive imports come from countries that currently have or are likely to have a carbon pricing policy (Houser and Bradley, 2008).

If the United States adopted a carbon tax, the natural mechanism to address imports from countries that do not have comparable carbon policies is through a border tax adjustment. Imported fossil fuels from countries with low or no carbon prices would be subject to the tax at the border. To reduce incentives for shifting carbon-intensive manufacturing to countries that do not impose a carbon price, the United States should also apply the carbon tax to the embodied carbon in certain carbon-intensive imports. In Metcalf and Weisbach (2008), my coauthor and I describe this modified origin approach in more detail.

Whether this policy would be administratively feasible, desirable, and legal under rules of the World Trade Organization are matters of some debate. It would clearly be administratively complex to collect a carbon tax on the carbon embedded in *all* imports. But the United States could apply a border tax adjustment to a small number of carbon-intensive imports like steel, aluminum, paper, chemicals, and cement. While it would be desirable to tax the imports on their actual carbon content, this content will vary from country to country, and so it may be more practical to set the tax adjustment at a level based on average domestic content. Countries could apply for a variance from the average rate by providing documentation that their exports to the United States have a lower carbon content.

Trade economists are generally skeptical of any proposal to apply tariffs on imports for social reasons. The essential and legitimate concern is that social policy might be used as a cover for protectionist policies. World Trade Organizations rules are clear that, in general, taxes on imports are permissible so long as the tax is on the product, rather than the processes and production methods. However, WTO has explicitly built into its rules exemptions for health and the environment (Article XX).[4] As long as the proposed border tax adjustment treats domestic production and imports equivalently, it would be hard to argue that a border tax adjustment has protectionist implications.

[4] Frankel (2005) argues that the language of the WTO's ruling on the U.S. ban on shrimp imports from countries not protecting endangered sea turtles also opens the door to the regulation of processes and production methods. Also see Frankel (2008).

An argument could be made that a border tax adjustment based on U.S. content circumvents the processes and production methods issue entirely. The issue, however, will only be resolved once a country implements a carbon tax with a border tax adjustment.

Similar issues arise with any policies to address leakage of economic activity to other jurisdictions in a cap-and-trade system. Stavins (2007) recommends requiring permits to be surrendered by importers of a selective number of carbon-intensive products. Similar issues of legality under the World Trade Organization rules, and of measurement of carbon content to determine the number of allowances to be surrendered upon import, arise with this system as with a carbon tax.

Conclusion

Nearly all economists on both sides of this instrument choice debate agree that a comprehensive carbon pricing policy using either a carbon tax or a cap-and-trade system strongly dominates a sectoral-based command-and-control regulatory approach on efficiency and distributional grounds. We can expand the pricing system beyond energy-related carbon emissions to capture something on the order of half of the other greenhouse gases at reasonable cost. Economists seem to be reaching agreement on some other points as well. Whether the United States implements a tax or permit system, it should put the point of compliance as far upstream as possible to reduce administrative costs. The country also needs to have a forthright discussion of the revenues that will be (or could be) generated with carbon pricing, with a particular focus on minimizing adverse impacts on low-income households. Finally implementing a carbon price—either through a tax or permit system—provides an opportunity to end current energy subsidies and regulatory programs that would no longer be needed with a meaningful carbon price.

In closing, let me address a common criticism of U.S. action on climate change. If the United States—or the United States along with other developed countries—reduces greenhouse gas emissions without participation by developing countries, it is observed that all we will have accomplished is a shift of production of carbon-intensive manufacturing to the developing world and no consequent drop in emissions. In short, global participation in greenhouse gas reductions is essential for solving this global problem. While this point is absolutely correct, it does not imply that the United States and other developed countries should not act before obtaining international agreement to reduce emissions. It is hard to imagine how we can get major developing countries to commit to greenhouse gas reduction if the United States, as the world's richest country, does not commit to significant greenhouse gas reductions.

While a U.S. program to reduce emissions of greenhouse gases is likely a necessary condition for a comprehensive international agreement to reduce emissions, it is by no means a sufficient condition. The United States could commit to a policy that includes border tax adjustments for carbon-intensive imports from countries that do not have a substantive emissions program and perhaps provide a timetable for commitment by major carbon emitting nations to join an international agreement. If, for example, China and other major emitting nations do not commit to significant emission reductions within the next 15 years, the U.S. and other developed nations could even promise to remove their tax or trading systems.

A U.S. carbon pricing scheme—whether in the form of a comprehensive carbon tax or cap-and-trade system—will be an enormous undertaking. It could end up covering emissions on the order of six billion metric tons of CO_2 equivalent—which would be roughly three times the annual covered emissions under the 2008–2012 phase of the EU's Emissions Trading Scheme. Nonetheless, it is time for the United States to enact a meaningful policy to reduce greenhouse gas emissions. Without the participation and leadership of the world's richest country and one of the leading emitters of greenhouse gases, it is difficult to imagine how the world can ever make meaningful progress on slowing and eventually stopping global warming.

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