DISCUSSION PAPER

July 2008 ■ RFF DP 08-26

A Tax-Based Approach to Slowing Global Climate Change

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RESOURCES
FOR THE FUTURE

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Abstract

In this paper, we discuss the design of carbon dioxide (CO_2) taxes at the domestic and international level and the choice of taxes versus a cap-and-trade system. A strong case can be made for taxes on uncertainty, fiscal, and distributional grounds, though this critically hinges on policy specifics and how revenues are used. The efficient near-term tax is at least \$5–\$20 per ton of CO_2 and the tax should be imposed upstream with incentives for downstream sequestration and abatement of other greenhouse gases. At the international level, a key challenge is the possibility that emissions taxes might be undermined through offsetting changes in other energy policies.

Key Words: Global climate change, CO_2 tax, cap-and-trade, policy design

JEL Classification Numbers: Q54, Q58, H23

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"The U.S. must engage in an energy efficiency program that takes effect without delay and has meaningful bite. As long as developing countries can point to the U.S. as a free rider there will not be serious dialogue about what they are willing to do. I prefer carbon and/or gasoline tax measures to permit systems or heavy regulatory approaches because the latter are more likely to be economically inefficient and to be regressive."

—Lawrence Summers, former U.S. Treasury Secretary, currently Professor at Harvard University (from Practical Steps to Climate Control, *The Financial Times* May 28, 2007).

"Frankly, a Kyoto-type framework—one with global quantitative emissions targets allocated among countries … is not feasible. The only approach that will fulfill the conditions and relieve countries' apprehensions regarding sovereignty and free riding is one in which all countries agree to penalize their carbon emissions in such a way that, over time, an internationally harmonized carbon price prevails. Consequently, the negotiation's focus would not be on emissions quotas but on the harmonized carbon-price trajectory.

Of course, carbon taxes (on burning fossil fuels) would provide the easiest way for countries to comply with the system, and each country could then decide what to do with the tax revenue. Some might make their carbon tax revenue-neutral by reducing other taxes. The regime would allow countries (or associations of countries such as the EU) to comply with the internationally agreed-upon carbon price by means of their own national cap-and-trade systems. It would also let poor countries move toward the agreed trajectory of carbon prices more slowly than rich countries.

If you're worried about climate change but don't like carbon taxes, think about the messy or even impossible alternatives!"

—**Ernesto Zedillo,** former president of Mexico, currently Director of the Center for the Study of Globalization at Yale University (from Carbon Prices, Not Quotas, *Forbes* March 24, 2008).

I. Introduction

There is widespread agreement on the desirability of a globally based effort to mitigate emissions of greenhouse gases (GHGs), particularly the primary gas, carbon dioxide (CO_2), with

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the ultimate objective of stabilizing atmospheric GHG concentrations.[1] Of course, considerable dispute continues regarding how rapidly to scale back global CO_2 emissions. For practical policy purposes, however, the immediate issue is how to develop an international climate policy regime with a robust emissions mitigation effort as its centerpiece, one that can progressively incorporate rapidly industrializing nations, and that can adjust over time as more is learned about the science, economics, and technological change that characterizes the climate change problem.

For mitigating GHG emissions, economists favor emissions taxes and cap-and-trade systems. Most of the policy discussion has focused on cap-and-trade systems, with the introduction of the European Union's Emission Trading Scheme (ETS), and the emphasis on trading in most climate bills currently pending in the U.S. Congress. However, as the quotes by Secretary Summers and President Zedillo suggest, and as we argue below, a potentially strong case can be made for carbon taxes. The policy landscape is not void of carbon taxes, as evident by the use of such taxes in northern Europe since the early 1990s, the recently implemented carbon tax in the province of British Columbia, and a couple of bills in the U.S. House of Representatives. And even if additional governments do not implement CO_2 taxes in the near term, it is important to assess the possible case for transitioning to a tax-based system over the longer haul. Thus, it is critical to understand how to design a CO_2 tax at domestic and international levels and to compare its advantages and disadvantages with those of a cap-and-trade approach. Because cap and trade is often heralded as a market-based approach in the political discourse, it is worth noting at the outset that both systems are equally market-based in the sense that their effectiveness relies in affecting market behavior through emissions pricing.

We begin this paper by comparing CO_2 taxes and emissions trading from a domestic perspective across a broad range of criteria of potential concern to policymakers.[2] Next, we

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[1] The Intergovernmental Panel on Climate Change (2007) concludes that warming of the Earth's climate system is unequivocal and that a delay in reducing GHGs significantly constrains opportunities to achieve lower climate stabilization targets. A U.S. National Academy of Sciences (2008) report states that "There is a growing concern about global warming and the impact it will have on people and the ecosystems on which they depend. […] Temperatures will likely rise at least another 2°F (1.1°C), and possibly more than 11°F (6.1°C), over the next 100 years. This warming will cause significant changes in sea level, ecosystems, and ice cover, among other impacts."

[2] We focus on CO_2 taxes for ease of exposition. As we discuss below, climate change policy should also target various other non-CO_2 GHGs. Most of the discussion here is from the perspective of a prototypical developed country; we touch only briefly on issues related to implementation and monitoring that may be relevant for less developed countries.

briefly discuss some further issues in the practical design of a domestic CO_2 tax as well as issues in implementing CO_2 taxes at the global level. We then offer some concluding remarks.

II. Issues in the Choice of Control Instrument—A Domestic Perspective

In choosing among alternative instruments, a wide array of criteria may be of concern to policymakers. These include cost-effectiveness, the ability to deal with uncertainty over emissions abatement costs, and the incidence of the emissions mitigation policy, particularly the distribution of costs borne by different household income groups and by industries. We discuss the appropriate stringency of domestic climate policy later.

Even evaluating policies on a single criterion alone can be tricky. For example, the overall cost and distributional impacts of CO_2 taxes depend critically on what the government does with the revenues collected from those taxes. Further, satisfying one criterion may limit the government's ability to address another criterion. For instance, using some CO_2 tax revenues to provide compensation to politically influential groups may raise the overall costs of the policy by reducing revenues that might otherwise have been available for cutting other taxes that distort economic activity. Finally, comparing CO_2 taxes and cap-and-trade systems in their pure forms does not do justice to the full spectrum of policy options. Policymakers may modify either instrument's design, at least to some extent, to exploit apparent advantages of the other instrument.

In this section, we consider each of the major criteria in turn and discuss to what extent, if any, they imply a strong case for preferring CO_2 taxes to other emissions mitigation instruments, primarily cap-and-trade systems.[3]

A. Cost-Effectiveness

We start with cost-effectiveness, using the more traditional and narrow definition of cost that encompasses only changes in economic efficiency in the markets directly affected by the emissions mitigation policy. This notion of cost essentially reflects the loss of benefits to fossil fuel users, less savings in production costs from reduced fossil fuel supply. Under this narrow definition, emissions taxes and cap-and-trade systems can essentially be viewed as equivalent

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[3] Goulder and Parry (2008), Aldy et al. (2008), and Hepburn (2006) also provide broad discussions of the literature on alternative emissions control instruments. Our discussion in this section draws most heavily from Goulder and Parry (2008).

instruments. This equivalency breaks down, however, when we account for abatement-cost uncertainty (section II.B), and for how policies interact with the broader fiscal system (section II.C).

In the context of the narrow definition, cost minimization requires equating marginal abatement costs across all emissions sources. These options include:

- Switching to fuels with lower, or zero, carbon content. In the power sector, for example, this would involve replacing coal-fired generation with generation from natural gas, nuclear, hydro, wind, and solar power.
- Adoption of energy-conserving technologies to lower fuel requirements per unit of economic activity. In the transportation sector, for example, this would include the incorporation of technologies to improve vehicle fuel economy. In the residential sector, it would include upgrading the efficiency of lighting, heating, and cooling systems as well as the adoption of more energy-efficient appliances.
- Reducing overall demand for energy-intensive activities by, for example, traveling less or dwelling in smaller homes.
- Sequestering carbon to partly offset emissions through carbon capture and storage technologies at coal plants or other industrial facilities and through the expansion of forested land or modification of agricultural techniques to sequester carbon in soil.

In principle, when all firms and households face a common price per unit of CO_2 embodied in fuels and energy-intensive products, then no additional policies can lower the total cost of attaining a specified policy goal. These cost-minimizing conditions could be largely achieved under a CO_2 tax applied upstream in the fossil fuel supply chain, with corresponding tax credits for downstream sequestration, like carbon capture and storage at coal plants. This tax, which would be levied in proportion to a fuel's carbon content, would be largely passed forward into the price of coal, natural gas, and petroleum products, and therefore ultimately embodied in the price of electricity and other energy-intensive products. This *carbon added tax* system, along the carbon chain, would work much in the same way as a typical value added tax under the standard credit–invoice system, along the value chain.[4]

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[4] The carbon taxes dating to the early 1990s in Denmark, Finland, Norway, and Sweden do not achieve cost-effective emissions mitigation because they allow for significant variation in the tax per unit of carbon by fuels and by sectors (Bruvoll and Larsen 2004; Vehmas 2005). In contrast, the British Columbia CO_2 tax imposes a uniform rate on carbon across different fossil fuels (Government of British Columbia 2008).

The same efficiency conditions could also be met under an upstream cap-and-trade system, under which firms require allowances to cover the carbon content of fuels they mine or process and the market price of allowances is established in permit trading markets. This price is then passed forward into fuel prices. With competitive markets, and appropriate crediting provisions for downstream sequestration, there is very little difference between emissions taxes and cap-and-trade systems in terms of the emissions mitigation that they encourage.[5]

Direct regulatory instruments, such as mandates to install specific emissions control or energy-saving technologies, or requirements for the performance of firm production, fail to meet the cost-minimizing criterion. Compared with a CO_2 tax or cap-and-trade system, and for the same economy-wide emissions goal, some abatement opportunities are overburdened under direct regulation, whereas others are underexploited or not exploited at all.[6]

B. Implications of Abatement Cost Uncertainty

Uncertainty over the future costs of emissions abatement is inevitable as costs will vary with fuel prices, the strength of domestic energy demand, unpredictable advances in energy-saving technologies, and so forth. Abatement costs, however, will also depend on the choice of emissions control instrument. CO_2 taxes fix the price of emissions, and therefore the marginal costs of abatement, while allowing the quantity of emissions to vary with economic conditions.

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[5] In practice, achieving cost-effectiveness may be more difficult under a cap-and-trade system in the early years because of additional informational requirements. Under a tax, the future emissions price is known, whereas under cap and trade, firms must project future allowance prices. To the extent that price expectations among firms differ, this may lead to a disparity in marginal abatement costs across emissions-reducing capital investments. Whether this significantly compromises the cost-effectiveness of emissions trading schemes has not been explored in the literature.

[6] Consider, for example, standards for the average fuel economy of vehicles in a manufacturer’s sales fleet. By itself, of course, this policy fails to exploit any emissions mitigation opportunities outside of the automobile sector. This substantially reduces the cost-effectiveness of the policy (relative to an economy-wide CO_2 tax) given that, in the United States for example, automobiles only account for one-fifth of nationwide CO_2 emissions (Energy Information Administration 2008). Nor does the policy encourage any downstream sequestration activities. Even within the automobile sector, the policy does not exploit emissions mitigation through reduced vehicle miles of travel because, unlike a gasoline tax, or a tax on the carbon content of gasoline, fuel economy regulations do not increase fuel costs per mile driven. Furthermore, unless fuel economy credits are tradable across firms, no automatic mechanism equates the marginal costs of improving fuel economy across different auto manufacturers. Austin and Dinan (2005) find that the long-run costs of reducing gasoline or, equivalently, CO_2 emissions, from automobiles, by around 10 percent, would be about 70 percent greater under tighter fuel economy regulations than under higher gasoline taxes.

In contrast, a pure cap-and-trade system fixes the quantity of emissions, leaving marginal abatement costs to fluctuate with economic conditions.

From the perspective of maximizing expected economic welfare, CO_2 taxes have an advantage over cap-and-trade systems. CO_2 taxes and cap-and-trade systems both affect the flow of emissions, although it is the atmospheric stock of gases that drive climate change damages. The stock changes slowly, because of the long atmospheric residence of CO_2 (on average about a hundred years). For example, the Mauna Loa record dating to 1959 shows that atmospheric CO_2 concentrations grow about 1 to 2 parts per million (ppm) annually, on a preindustrial base of about 270 ppm. Because global emissions in any given year have a proportionately small impact on the stock of CO_2, the marginal benefits of abatement are essentially perfectly elastic.

Figure 1 illustrates the potential welfare effects of ex ante efficient policies in this setting (based on Weitzman 1974). MC^E is the expected marginal cost schedule for emissions abatement, and MB is the marginal benefit from abatement. If marginal costs turn out to be higher than anticipated, MC_H, then the efficient amount of abatement is Q_H, whereas if costs are lower than expected, MC_L, the optimal abatement is Q_L. A Pigouvian emissions tax of T*, equal to marginal benefits, automatically generates these efficient abatement levels, regardless of the position of the marginal cost curve. In contrast, under a fixed emissions cap of Q^E, abatement will be excessive if marginal costs are higher then expected, or too low if marginal costs are lower than expected, resulting in deadweight losses (DWL), relative to the emissions tax, shown by the shaded triangles in Figure 1. In fact, the welfare differences between carbon emissions taxes and cap-and-trade systems can be striking. For example, simulations in Pizer (2002) and Newell and Pizer (2003) suggest that a CO_2 tax could result in welfare gains up to five times those of the expectation-equivalent cap-and-trade system.[7]

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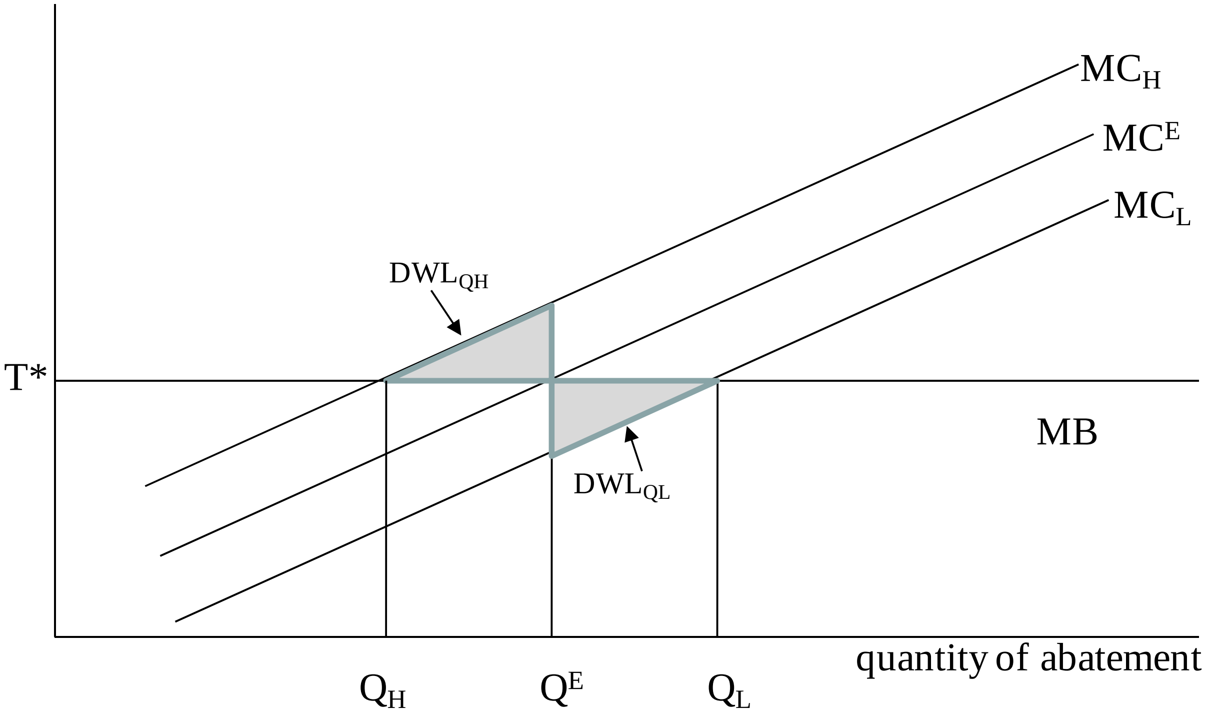
[7] Uncertainty over the marginal benefits from abatement does not affect these results as long as this is independent of the uncertainty over marginal abatement costs (Stavins 1996). This is a reasonable approximation for the near term.

Figure 1. Illustration of the Effects of Abatement Cost Uncertainty on Welfare



Alternatively, if the policymaker aims to minimize the present discounted value of costs for limiting emissions released into the atmosphere over a long period of time, then emissions taxes again have an advantage over cap-and-trade. An emissions tax rising at the rate of interest over time (net of the "depreciation rate" of atmospheric accumulations of emissions) will equate the present value of marginal abatement costs across different periods. In contrast, under a pure allowance system, abatement will be excessive (and allowance prices too high) in periods when meeting the fixed cap is more costly than average, whereas abatement will be too low in periods when the marginal costs of meeting the cap are lower than average.

However, modifying a cap-and-trade system to incorporate some of the price-stabilizing characteristics of an emissions tax can mitigate some of the welfare differences between the pure forms of these two instruments. For example, a hybrid tax-allowance approach, often referred to as a safety valve, could reduce price volatility (Kopp et al. 1997; McKibbin and Wilcoxen 1997; Jacoby and Ellerman 2004). Under such an approach, the government would agree to sell an unlimited number of additional allowances at a predetermined price into a cap-and-trade market. If emissions trading results in allowance prices below this predetermined price, then the market behaves as a normal cap-and-trade regime. The safety valve serves as a ceiling on the allowance price, such that, if prices increase enough that it becomes economic for firms to purchase safety valve allowances instead of buying allowances at even higher prices, then the system effectively transforms into a tax: firms purchase safety valve allowances, thereby relaxing the cap on the program's emissions.

In a related policy context, the safety valve has already become a part of implementing renewable energy goals. The Massachusetts renewable portfolio standard for the state's power sector allows utilities to buy and sell renewable energy credits. In lieu of holding sufficient credits to satisfy the standard, utilities may also comply with their regulatory obligation by making Alternative Compliance Payments, initially set at $50 per megawatt-hour in 2003 and adjusted annually for inflation (Massachusetts Division of Energy Resources 2008).

The basic model of cap and trade allows for firms to equate marginal costs of abatement across all sources. Modifying cap and trade to allow intertemporal emissions trading would provide the opportunity for firms to equate (discounted) marginal costs over time and facilitate efforts to smooth out year-to-year allowance price volatility. Unfettered intertemporal trading would allow firms to bank allowances for use later (e.g., when current prices are low and expected future prices are high) and to borrow allowances from future periods when future prices are expected to be lower than current prices.[8] The European ETS now allows full banking of emissions allowances; however, firms are not allowed to borrow allowances from future policy commitment periods. This could create problems in the near term, before firms have accumulated a substantial bank of allowances, as it leaves the system vulnerable to shocks, such as a jump in natural gas prices that would raise the costs of fuel switching in the power sector.[9]

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[8] Borrowing could take two forms. First, the government may allocate multiple years' worth of permits at the beginning of the cap-and-trade system, and firms would have discretion regarding when to use permits of various vintages. Second, firms could go to the government and borrow permits that would then translate into smaller future allocations.

[9] The banking provisions were introduced after the pilot phase of the ETS witnessed quite volatile allowance prices. But even with banking, CO_2 prices continue to fluctuate, with the maximum daily allowance price about 33 percent higher than the minimum price over the first three-and-a-half months of 2008 (allowance prices are posted at www.pointcarbon.com). To the extent that this causes marginal abatement costs to vary substantially within a period of just a few months, the cost-effectiveness of the cap-and-trade system is significantly undermined.

A further alternative would be to attempt to stabilize the allowance market through a "Climate Fed" that could counteract severe price volatility through buying or selling allowances to the market in times of unusually high or low prices. Several U.S. domestic climate policy bills envision this type of scheme. One could consider a variety of tools at the disposal of the Climate Fed, such as relaxing emissions caps, reallocating caps by borrowing emissions from future periods to augment current-period allowance allocations, or increasing the amount of offsets that would be allowed into the cap-and-trade regime.

C. Cost-Effectiveness Accounting for Fiscal Interactions

The overall economic costs of emissions mitigation policies, and the choice among different instruments, is further complicated by how these policies interact with distortions elsewhere in the economy created by the broader tax system.

The environmental tax literature emphasizes that emissions taxes potentially impact tax distortions in economy-wide factor markets—particularly those in the labor market created by income and payroll taxes—in two main ways (e.g., Goulder 1995). First is the "revenue recycling effect." Using CO_2 tax revenues to reduce existing factor taxes generates a gain in economic efficiency equal to the increase in labor (or capital) supply, multiplied by the wedge between the gross factor price and the net-of-tax factor price.[10] The potential welfare gains, even from very small increases in the supply of capital and labor, could be relatively large because the benefits of tax rate reductions apply to the entire economy, whereas the costs of abatement accrue primarily to the energy sector (e.g., Parry et al. 1999).

Second, however, an offsetting effect would occur. As firms pass CO_2 taxes forward into higher energy prices, this drives up product prices in general, thereby depressing the real return-to-work effort and savings—in other words, the amount of goods that people can buy with their take-home wages or income from savings. Reducing the buying power (real returns to) capital and labor would depress labor supply and capital accumulation. This so-called "tax-interaction effect" would compound the current tax distortions in factor markets and increase the costs of the climate policy.

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[10] The gross factor price reflects the marginal value of production to firms from the last unit of the factor, whereas the net factor price reflects the marginal cost of factor supply to households (e.g., the marginal cost of foregone nonmarket time). This applies at least when factor markets are competitive. Factor market impacts are more opaque in the presence of institutional wage setting, which is important in certain European labor markets (Bosello et al. 2001).

A large literature on these two effects has evolved over the past 15 years, and most analyses find that the costly tax-interaction exceeds the beneficial revenue-recycling effect, implying that the overall costs of carbon taxes are somewhat larger than the costs of carbon reductions in fossil fuel and energy markets (e.g., Bovenberg and Goulder 2002). However, the magnitude of the revenue-recycling effect is highly sensitive to the details of the tax shift. For example, if the CO_2 tax revenue is predominantly used to reduce taxes on capital income, the revenue-recycling effect is larger (as capital taxes are thought to involve higher distortionary costs at the margin than labor taxes) and could exceed the tax-interaction effect (Bovenberg and Goulder 1997). Alternatively, if CO_2 tax revenue is used to cut marginal personal income tax rates, this can also raise the revenue-recycling effect above the tax-interaction effect by (slightly) reducing distortions between ordinary spending and tax-favored spending on home ownership, employer medical insurance, and so forth (Parry and Bento 2000). On the other hand, using revenue to raise personal income tax thresholds or to introduce similar threshold exemptions for payroll taxes would produce a smaller revenue-recycling benefit because it would encourage more labor force participation but not additional effort on the job or longer work hours.

In contrast to a revenue-neutral CO_2 tax, a cap-and-trade program with gratis allocation incurs much higher total costs. The government foregoes collecting revenues when it transfers free allowances to firms, but the allowance price yields the same tax-interaction effect—by increasing energy costs—as if an emissions tax were imposed at the same price. The cost advantage of (revenue-neutral) emissions taxes can be substantial. For example, a $10-per-ton CO_2 tax ($37 per ton of carbon) could lower U.S. emissions by 5–10 percent and raise annual revenues of approximately $60 billion in the near term. If the government used this revenue to reduce income taxes, based on typical assumptions in the literature, the CO_2 tax would deliver roughly $20 billion per year in cost savings over an equivalent cap-and-trade system that did not exploit a similar revenue-recycling effect.[11]

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[11] Two caveats to this argument must be considered. First, even cap-and-trade systems with entirely free allowance allocation can raise a limited amount of revenue for the government indirectly (perhaps around 40 percent of that raised directly under the equivalent emissions tax). This occurs as firms receiving allowances with market value for free experience an increase in their equity values, which, in turn, leads to higher corporate taxes and ultimately higher income and capital gains taxes for individual shareholders. Second, the tax-interaction effect may be somewhat weaker under freely allocated permits than under emissions taxes in countries that retain some price regulation in the power sector (such as the United States). Electric utilities subject to such regulation cannot pass through the market value of freely received permits into higher generation prices (Burtraw et al. 2002); this, in turn, weakens the policy's impact on the overall price level, and hence limits the reduction in real factor returns and the tax-interaction effect.

Of course in practice, CO_2 revenues might be squandered in special interest spending, rather than used to cut other distortionary taxes (or finance other socially desirable public spending), thereby reducing, and possibly even reversing, the sign of the revenue-recycling benefit. Conversely, a cap-and-trade program could exploit the revenue-recycling effect if allowances were auctioned off by the government. Again, therefore, whether a strong case can be made for emissions taxes over cap and trade depends critically on the details of the accompanying legislation.

The plan for the European ETS is to transition to a fully auctioned allowance system by 2020 (CEC 2008), incorporating into the system one of the key attractions of the emissions tax alternative. It is not yet clear, however, how all this new revenue will be used, as the plan does not specify revenue neutrality. In contrast, Sweden began using carbon tax revenue in 2000 to offset labor taxes (Government of Sweden 2005). British Columbia implemented a CO_2 tax of $10 per ton in July 2008, with a ramp-up of $5 per ton CO_2 per year until reaching $30 per ton in 2012. The BC carbon tax program stipulates revenue neutrality, and the only permissible form of revenue recycling is the reduction of taxes borne by individuals and businesses (Government of British Columbia 2008).[12]

D. Distributional Considerations

For reasons of fairness and practical feasibility, policymakers have expressed concern over the distributional burdens of domestic mitigation policies on different household income groups and on energy-intensive industries. Although pure emissions taxes and cap-and-trade systems have very different distributional implications, again the government can modify either instrument to mimic, at least in part, any distributional advantage of the other instrument.

Distributional Impacts across Household Income Groups

Low-income households are more vulnerable to increases in the price of energy-intensive goods, such as electricity, home heating fuels, and gasoline, because they spend a larger share of their budget on these items compared with wealthier households. The regressivity of CO_2 taxes—reflected by the greater burden-to-income ratio for lower-income groups than for higher-income groups—varies by the time frame of measurement. Generally, analysts prefer using a

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[12] The revenues from Norway's CO_2 tax go to general revenues, so it is not clear whether this ultimately results in greater public spending or reduced rates for other taxes (Daugbjerg and Pedersen 2004).

measure of lifetime income in incidence analysis, as this better reflects households' long-run consumption possibilities, though measuring lifetime income presents difficult technical and data challenges. Studies that use a measure of lifetime, as opposed to annual, income find that CO_2 taxes are less regressive than static analyses suggest (see Parry et al. 2006 for a review).

Traditional cap-and-trade systems with free allowance allocation provide no mechanism for addressing concerns about the disproportionate burden of higher energy prices on lower-income households. In fact, they make the problem worse by widening the disparity in burden-to-income ratios among lower- and higher-income households. The distribution of free allowances with market value raises firm profits and equity values; this ultimately benefits shareholders, who tend to be concentrated in upper-income groups. In fact, Dinan and Rogers (2002) find that a cap-and-trade system with free allocation mitigating CO_2 emissions by 15 percent overcompensates the wealthiest households, as their additional capital income substantially exceeds the burden on them from higher energy prices.

In contrast, under a CO_2 tax or auctioned allowance system, policymakers can address fairness concerns, at least in part, by recycling some of the revenue in ways that disproportionately benefit low-income households, such as reductions in payroll taxes, or increases in income tax thresholds. For example, Metcalf (2007) outlines a scheme for a \$15 per ton tax on CO_2 emissions (\$55 per ton of carbon) in the United States, with revenues funding payroll tax rebates in a manner that imposes the same approximate burden-to-income ratio across income deciles. Some elderly or other nonworking households, however, do not benefit from payroll tax reductions and may require compensation through other means, such as targeted energy assistance programs. Recycling CO_2 tax revenues in ways that disproportionately help lower-income households may involve some sacrifice of economic efficiency compared with across-the-board reductions in distortionary taxes, although the potential empirical magnitude of these losses has not received attention in the literature.

Distributional Impacts on Energy-Intensive Firms

Some have advocated gratis allowance allocations to the business community to effectively secure their support for climate change policy (e.g., McKibbin and Wilcoxen 2007). Clearly, providing some compensation for politically influential industries most affected by federal climate policy for their loss of equity value might be part of the political deal making needed to move legislation forward. To the extent that firms' (short-run) supply curves slope upward rather than being perfectly elastic, some of the burden of the emissions mitigation policy may come at the expense of lower producer surplus—through a reduction in producer prices—rather than passing forward the entire burden in higher consumer prices.

Under a cap-and-trade system, the government can compensate firms by giving them an allowance allocation with a market value equal to their potential reduction in equity value or producer surplus. A domestic CO_2 cap-and-trade program with free allocation of 15–20 percent of total emissions allowances could keep fuel suppliers and power generators whole (Bovenberg and Goulder 2001; Smith et al. 2002).[13] Providing such compensation has a cost, as it reduces the amount of revenue that could potentially finance reductions in other distortionary taxes. For example, Bovenberg and Goulder (2001) estimate that the overall costs of freely distributing 15–20 percent of allowances would be about 7 percent greater than a 100 percent auction to finance reductions in distortionary taxes. Obviously, the total cost increases much more under a more aggressive emissions mitigation program that requires greater compensation.

The government could pursue a similar approach under a CO_2 tax by providing inframarginal exemptions. For example, the tax could apply only after a firm's emissions equal to 15–20 percent of historic emissions, allowing for full compensation just as if the firm had received 15–20 percent of emissions allowances for free under a cap-and-trade program.[14]

In some cases, emissions sources have been exempt outright from CO_2 taxes. For example, Norway's CO_2 tax, implemented in 1991, covered about only two-thirds of the economy's emissions, and a reform of Sweden's CO_2 tax in 1993 exempted industrial sources from paying carbon taxes on electricity and fossil fuels. These exemptions obviously raise the overall costs of the CO_2 tax, relative to a comprehensive tax, by failing to exploit low-cost abatement opportunities in the exempt sector.

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[13] Compensation would become more difficult (i.e., a greater share of allowances would have to be given away for free) as the emissions cap is progressively tightened over time, and beyond some point, even giving away 100 percent of the allowances would not be sufficient to fully compensate firms. This issue might be addressed through excess compensation in the early years of the program (e.g., Stavins 2007). Progressively phasing out compensation over time makes sense because it avoids potential difficulties in updating the share of the allowance cap going to different firms, as different firms expand or contract at different rates in the future.

[14] Compensation for firms lying downstream of the point of regulation (e.g., power companies) could also be provided under either policy through free allowance distribution or temporary relief from other taxes.

E. Summary

The case for preferring CO_2 taxes to cap-and-trade systems depends critically on several design choices. If cap-and-trade programs incorporate provisions to contain allowance price volatility and to transition to full revenue-neutral allowance auctions, then a CO_2 tax may not strongly dominate a cap-and-trade regime. If the only politically viable type of cap-and-trade system is of the pure form, however, then CO_2 taxes are a far better alternative, as long as revenues are used judiciously, and large emissions sources are not exempt from the tax.

III. Designing a Domestic CO_2 Tax

We now discuss further practical issues in the design of a domestic CO_2 tax: setting the emissions price (tax level); choosing the point of regulation; addressing emissions leakage from industrial relocation; incorporating non-CO_2 GHGs and downstream sequestration activities; and identifying complementary technology policies.[15]

A. Tax Level

Standard economic welfare-maximizing theory recommends that the appropriate CO_2 tax should reflect the world consequences from the estimated future climate change impacts per ton of current CO_2 emissions. These consequences encompass damages to agriculture, the impacts of (and costs of protecting against) rising sea levels and increased storm intensity, health effects (e.g., from the possible spread of tropical disease), ecological disruptions, the risks of major disruptions to world output from more extreme climate scenarios, and so forth. Predicting and valuing these impacts is extremely difficult and controversial (e.g., Mendelsohn 2005).

For example, there is substantial uncertainty over the extent and timing of future global warming, as well as the accompanying climate changes that might be experienced at a regional level. Data available for quantifying the nonmarket impacts of climate change, such as migration of ecosystems, is very sparse. The appropriate discount rate for valuing the very long-run impacts of today's emissions is disputed.[16] And uncertainty over the pace of future economic

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[15] Kopp and Pizer (2007) and Stavins (2007) also provide broad discussions of the literature on designing emissions control instruments.

[16] Impacts are very long range, not only because emissions have a very long residence time in the atmosphere, but also because it takes decades for global temperatures to fully adjust to a change in atmospheric accumulations because of gradual heat diffusion processes in the oceans.

growth and technological development makes it very difficult to project the vulnerability of the world to climate change occurring several decades or more from now. Incorporating the risks of catastrophic climate change, such as the potential for a feedback effect or nonlinearity in the climate system to result in extreme warming scenarios, is most difficult of all.

Despite all of these challenges, an evolving valuation literature attempts, albeit very roughly, to put a price on CO_2 emissions under different future climate scenarios. Most estimates put the future damages from today's emissions at the equivalent of around \$5 to \$20 per ton of CO_2 (\$20 to \$75 per ton of carbon) (Tol 2007). The most comprehensive estimates, developed by Nordhaus and Boyer (2000), and updated in Nordhaus (2008), put the optimal global price at \$9.5 per ton of CO_2 in 2015, rising at about 2 to 2.5 percent per year to \$23 per ton by 2050 and \$56 per ton by 2100 (prices are in 2005 dollars).[17] Table 1 illustrates what this level of near-term CO_2 price would imply for certain energy and fuel prices.

Table 1. Equivalency of Units

Tax of \$10 per ton of CO_2 equals:	
\$36.7	Per ton of carbon
\$4.77	Per barrel of oil
¢8.80	Per gallon of gasoline
¢2.29	Per liter of gasoline
¢0.78	Per kilowatt-hour of electricity

Source: www.epa.gov/solar/energy-resources/calculator.html.

Note: The CO_2 price can also be expressed per million BTU of fuel. For example, a \$10 CO_2 price amounts to \$1.08, \$1.06, and \$1.03 for lignite, sub-bituminous, and bituminous coal, respectively, and ¢87 for residential fuel oil, ¢82 for crude oil, ¢79 for gasoline, and ¢59 for natural gas, where all units are per million BTU of fuel.

Some studies, however, suggest substantially higher near-term emissions prices. In particular, Stern's (2007) central estimate of the current marginal damage per ton of CO_2 is around \$85. Stern's (2007) estimates of the total damages from a given amount of warming (expressed as a percentage of world gross domestic product [GDP]) are broadly similar to those in Nordhaus and Boyer (2000), although the relative contributions of market impacts, nonmarket effects, and catastrophic risks is strikingly different in the two studies. As discussed extensively

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[17] Roughly speaking, the optimal tax rises at the rate of growth in world output potentially affected by future global warming. At first glance, one might think that the tax should increase at a faster rate, given that damages are convex in the extent of climate change. However, in Nordhaus and Boyer (2000), this effect is roughly offset, because warming is taken to be a concave function of the atmospheric concentration of GHGs.

in Nordhaus (2007), marginal damages are dramatically larger in Stern (2007) because disutility to future (unborn) generations is not discounted in the latter study and this greatly magnifies the present value of distant damages, especially when they become very large after 2100.[18]

Weitzman (2008) provides an alternative perspective on catastrophic damages.[19] He shows that, under a plausible utility function, we cannot put an upper bound on marginal damages when there is a positive, albeit a very small and very distant, probability of destroying the planet as we know it—by his definition, this is the possibility of extreme warming reducing worldwide consumption by 99 percent indefinitely.[20] Analysts who are broadly sympathetic to this viewpoint tend to reject attempts to assess Pigouvian emissions taxes and instead focus on least-cost emissions pricing trajectories consistent with ultimately stabilizing atmospheric GHG concentrations at alternative target levels.

Although a number of modeling groups have projected such pricing paths, we focus here on a study by Clarke et al. (2007) employing three widely respected energy–economic models for the U.S. Climate Change Science Program. The models generated carbon price trajectories consistent with stabilizing atmospheric CO_2 concentrations at 450, 550, and 650 ppm (current concentrations are about 385 ppm, compared with preindustrial levels of about 270 ppm). Under central projections of the Intergovernmental Panel on Climate Change, and accounting for various non-CO_2 greenhouse gases, these stabilization targets would result in mean projected long-run warming of about 2.0, 3.0, and 3.6^{o}C, respectively, above current levels.

Assuming globally cost-effective emissions mitigation, Clarke et al. (2007) estimate that the price on CO_2 emissions should rise to \$40–\$95, \$5–\$30, or \$1–\$10 per ton of CO_2 by 2025,

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[18] The appropriate rate at which to discount future global warming damages is extremely contentious—essentially it is a philosophical issue that is not going to be resolved any time soon. In our view, economists should objectively lay out the case for and against different assumptions and their implications for policy and let the policymakers decide how to proceed. Low, or zero, discount rates might be appealing on ethical grounds, given that damages will affect people who have not been born yet. But applying these rates in other contexts leads to perverse implications. For example, if applied retrospectively, all previous (low-consumption) generations should have been made even worse off to make our (high-consumption) generation better off.

[19] In Nordhaus and Boyer (2000) and Stern (2007), catastrophic damages are quantified based on the subjective views of experts concerning the risks of losing, in perpetuity, a large portion (though not an infinitely large portion) of world GDP for different levels of warming.

[20] Weitzman (2008) also suggests that cost–benefit analysis is not a useful tool for guiding climate policy when uncertainty surrounds both the variance and the mean temperature change (or its effects on economic activity). In this “fat-tails” case, the outcome of cost–benefit analysis is highly sensitive to rather arbitrary modeling choices about things that we know little about, namely climate damage functions.

respectively, to be consistent with these three stabilization targets, and continue rising at around 3–5 percent per year thereafter (in real dollars).[21] The latter two price ranges are broadly consistent, at least in the near term, with those implied by the damage assessment studies that employ market discount rates. In striking contrast, the prices for the target of 450 CO_2 ppm are far more aggressive.

A critical caveat to these projections is that marginal abatement costs are equated across all emissions sources worldwide and across time. For example, to the extent that rapidly industrializing nations, such as China, do not fully participate in international emissions control, emissions prices in developed countries must be greater to meet the stabilization targets. Indeed, one of the modeling teams showed in subsequent work that a 450-ppm goal may not be feasible if China does not mitigate its CO_2 emissions before 2050 (Edmonds et al. 2007).

In summary, most analysts fall into one of two broad camps. Some analysts favor relatively moderate emissions pricing in the near term, with a progressive ramp-up over time, while also preserving the flexibility to ratchet up the price as more information emerges on the risk of catastrophes. This position is based on a balancing of damage estimates (discounted at market interest rates) and abatement costs. Other analysts favor far more aggressive emissions pricing immediately, to put us on a path toward rapid stabilization of atmospheric concentrations. This position is based on low discounting of long-range impacts and/or the view that cost–benefit analysis cannot handle the possible risks of extraordinarily catastrophic damage. The bottom line is that, following the European Union, Japanese and U.S. policymakers need, at the very least, to get a moderately scaled emissions pricing program underway.

B. Further Design Issues

Point of Regulation

Governments should levy a CO_2 tax upstream in the fossil fuel supply chain as this covers all possible sources of emissions when fuels are later combusted; therefore, it exploits all potential opportunities for emissions abatement. The tax should apply to coal produced at the

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[21] The widely different projections for required emissions prices stem from different assumptions about emissions growth in the absence of policy, the development of new technologies such as carbon capture and storage, the scope for substituting into nuclear and renewables in power generation, and the uptake of atmospheric CO_2 from the oceans and biosphere.

mine mouth, petroleum used by refineries and imported petroleum products, and natural gas entering the pipeline system.

In the European Union's ETS, as well as some cap-and trade systems proposed in U.S. climate bills, the regulatory system focuses on downstream users of fossil fuels rather than upstream fuel producers. Downstream programs may be attractive to policymakers as they represent a natural extension of existing pollution regulations focusing on the power sector and major industrial emissions sources. These systems cover only around one-half of economy-wide CO_2 emissions as they exclude transportation and small-scale emissions sources (Pizer 2007). However, their costs, for a given economy-wide emissions reduction, may not be that much greater than the alternative upstream program. This is because they still cover the power sector, which has a disproportionately large share of low-cost abatement opportunities. Moreover, emissions outside of the covered sector can still be regulated through other means, such as higher fuel taxes.

A further advantage of upstream programs is their administrative simplicity. An upstream CO_2 tax in the United States or Europe would require regulation of only around 2,000–3,000 entities (Hall 2007). The quantity of fuels produced is readily observed and the carbon content varies moderately at most within a fuel type (e.g., across bituminous, lignite, and anthracite coal). The costs of monitoring a truly comprehensive downstream program would be daunting as there are literally hundreds of millions, if not over a billion, individual GHG emissions sources, ranging from vehicles to homes to factories to farms. For this reason, the ETS is limited to 10,000 or so entities with "big smokestacks" —power plants and factories with large industrial boilers (Hall 2007).

International Emissions Leakage and Competitiveness

Energy-intensive industries competing in global markets (e.g., steel, cement, and aluminum) represent about one-sixth of CO_2 emissions for a developed country like the United States (Energy Information Administration 2008). Morgenstern et al. (2007) found that production costs for these broad industry groups would increase by around 1–2 percent, for each \$10 increase in the CO_2 price, through higher input prices for electricity, fuels, and materials. This is probably minor relative to other factors governing the decision of whether to relocate plants overseas in countries where carbon is not priced (e.g., the exchange rate risk or the greater costs of transporting products back to the domestic market). Consequently, emissions leakage—that is, the increases in emissions elsewhere as footloose firms relocate abroad—should be of relatively modest concern from an efficiency perspective.

Nonetheless, domestic firms may still exert political pressure to prevent any “unfair” deterioration in their competitive situation compared with foreign suppliers in countries without climate policies. One way to address these concerns might be to charge fees on imported goods covering the embodied carbon in those products. Conversely, U.S. exporters selling in foreign markets might be rebated for domestic taxes paid (by upstream firms) on the embodied carbon of those products to prevent their competitiveness from deteriorating. However, measuring embodied carbon in finished products, especially those produced in industrializing nations, would be contentious and possibly open to abuse by domestic industries seeking protection for other reasons. In addition, import taxes and export credits may also run afoul of international trade agreements, or may ignite a trade war, thereby jeopardizing recent advances in trade liberalization.

Non-CO_2 GHGs

Including non-CO_2 GHGs into an emissions mitigation program is important. In the United States, these gases currently account for about 20 percent of total GHGs, with all gases expressed in terms of their lifetime warming potential in CO_2 equivalents. At the global level, non-CO_2 GHGs account for about one-third of total GHGs; although, without mitigation policy, they will likely grow more slowly in the future than CO_2 emissions (Clarke et al. 2007). Some of these gases (e.g., vented methane from underground coal mines and fluorinated gases used in refrigerants and air conditioners) could be monitored and incorporated into an emissions tax system based on their relative warming potential.

Methane and nitrous oxides from landfills, manure management, and soil management might be incorporated into an emissions tax system through tax credits. Effectively, this provides a subsidy for emissions reductions, appropriately set at the same rate as the corresponding emissions tax. To qualify for such a subsidy, the onus would fall on the individual entity to demonstrate valid emissions reductions relative to what their emissions would have been without the subsidy. This takes much of the administrative burden off of the regulator. Other emissions sources, which account for about one-third of non-CO_2 GHGs in the United States (e.g., methane from ruminants), are especially difficult to monitor, and may not be feasible to incorporate into an emissions tax system.

Incentives for Downstream Sequestration

Extensive research is underway in the public and private sectors to develop technology that would capture a large share of CO_2 emissions from coal plants and other major stationary emissions sources and store the CO_2 underground (e.g., in depleted oil reservoirs or other geological formations) by retrofitting existing plants or reconfiguring the design of new plants. Should this technology be successfully developed, tax credits could provide incentives for its adoption. Deutsch and Moniz (2007) suggest that the price of CO_2 would need to be at least $25 per ton to make capture technologies viable for new plants, and even higher for retrofitting of existing plants. An argument might be made for initially setting the tax credit per ton of CO_2 sequestered at or above this threshold, even if the near-term price on economy-wide emissions is below this level. This would help encourage wider diffusion of the technology as well as learning by doing that may lead to spillover benefits to later adopters of the technology.

Biological sequestration may provide another cost-effective way to mitigate CO_2 emissions, although estimates of the scope for converting cleared land into forests vary in the literature (e.g., Stavins and Richards 2005). Conceptually, farms that increased forestland coverage would receive a tax credit or subsidy, whereas those that shifted from forests to agriculture would pay a tax. According to Sedjo and Toman (2001), a national CO_2 tax system for the United States could feasibly incorporate forestry, given that transitions between forest and agricultural land in the absence of any CO_2 policy are relatively small. Remote sensing satellites could monitor land use changes and aircraft photography could generate estimates of stand species composition. The appropriate CO_2 tax or subsidy could then be calculated based on tree species and the age of the tree in the growth cycle.

Complementary Policies To Promote Technological Innovation

Clearly, the key to meeting the challenge of stabilizing the climate over the long run, at an acceptable cost to society, relies on the future development of technologies that will radically reduce the emissions intensity of economic activity (Newell 2008). In practice, however, designing policies to promote such research and development (R&D) activity, and the diffusion of new technologies, is quite difficult.

First, one must consider whether the government should impose stiffer carbon prices to create strong incentives for induced innovation in clean technologies. This issue is not entirely resolved in the economics literature. In principle, setting taxes in excess of the marginal damage from emissions might be warranted if the losses from excessive near-term abatement were more than offset by efficiency benefits from encouraging more clean-technology R&D. This would require the returns to society from extra innovation to exceed the private returns enjoyed by the firms conducting the R&D. The social returns probably do exceed the private returns, and by a potentially large amount, because of the spillover benefits of new knowledge. In fact, the empirical literature suggests that the magnitude of such spillovers is large for general innovation (e.g., Griliches 1992; Mansfield 1985; Levin et al. 1988; Jones and Williams 1998).

Nonetheless, some studies (e.g., Nordhaus 2002; Goulder and Schneider 1999) suggest that induced innovation has only a modest effect in setting the appropriate tax on CO_2. This reflects the fact that firms already have ongoing incentives to develop more fuel efficient vehicles, power plants, and so forth, and carbon pricing has a relatively moderate impact on enhancing these incentives. Moreover, extra R&D effort in the energy sector will probably crowd out socially valuable innovative effort elsewhere in the economy through the bidding up of research input prices, thereby limiting overall efficiency gains from induced innovation. Two caveats apply here: the models do not really capture incentives for transformative technologies (e.g., carbon capture and storage and plug-in electric vehicles) and they do not include climate change benefits from the adoption by other countries of U.S.-developed technologies.

Rather than setting stiff carbon prices, however, most analysts recommend targeting technology spillovers through more direct measures aimed at stimulating research.[22] Unfortunately, the available literature provides limited guidance on just how much extra energy-related R&D should be stimulated and which instrument—among R&D subsidies, technology prizes, and strengthened patent protection—should be used (e.g., Wright 1983). Some analysts argue that, even after the development of new technologies, further incentives are needed to encourage technology diffusion, such as vehicle fuel economy regulations or energy efficiency standards for household appliances. Such policies might be warranted in the presence of additional market failures (e.g., consumer undervaluation of energy efficiency improvements). Whether such additional market failures exist and their potential magnitude, however, remains an unsettled issue in the literature.

C. Summary

At a domestic level, designing a CO_2 tax is fairly straightforward, especially if imposed upstream in the fossil fuel supply chain as a carbon-added tax. Incorporating at least some non-CO_2 GHGs into the tax system is quite feasible, as is providing incentives for downstream geological and biological CO_2 sequestration. The main difficulties lie in deciding the tax level

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[22] In general, it is better to target each market failure (i.e., the emissions externality and the technology spillover externality) with two separate policy instruments, rather than just one instrument (Fischer and Newell 2008; Goulder and Schneider 1999).

and how rapidly it should escalate over time, as well as ensuring the productive use of revenues, in the presence of pressure for spending to satisfy special interests.

IV. CO_2 Taxes at a Global Level

We now turn to issues in the development of an international architecture based on CO_2 pricing. In particular, we discuss implementation issues and the relative ease or difficulty of reaching international agreements with tax- and quantity-based instruments. We focus on a multilateral "top-down" approach to climate policy agreements where countries attempt to reach agreement on the CO_2 tax rates they will each impose or targets for emissions control. Many of the issues are not so pressing if international climate policy emerges unilaterally from the bottom up, with countries developing their own targets and policy instruments either to set an example, or to follow an example set by other countries.

To be successful, any international climate agreement needs to meet a number of key criteria (Aldy and Stavins 2007a). These include cost-effectiveness, equity, broad participation, ease of reaching agreement on taxes or emissions targets, verification of member compliance with the agreement, and domestic institutional capability to implement the policy. We take each of these in turn. As we discuss, the first three criteria for a successful climate control agreement could, in principle, be met under either tax- or allowance-based approaches. And although it may be more difficult both to reach, and to implement, an international permit-trading system, concerns about emissions control effectiveness being compromised by other surreptitious policy adjustments pose greater challenges under the tax-based regime.[23]

A. Cost-Effectiveness

At any given time, cost-effectiveness requires that the marginal costs of abatement are roughly the same across different countries. In a dynamic sense, it also requires that marginal abatement costs are roughly equated, in present value terms, across current and future periods (or that they are equated with marginal emissions damages under a welfare-maximizing approach).

The cost-effectiveness condition can be met if all countries impose the same tax rate on CO_2—and the same tax on other GHGs and credits for sequestration—and the tax rate rises at the

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[23] As brought to our attention by Jon Strand, the potential for rent extraction by the Organization of the Petroleum Exporting Countries (OPEC) cartel is greater when facing a cap set by energy-importing countries than when facing an importer carbon tax. The cap is an effective coordination mechanism.

rate of interest over time (or with the growth rate in marginal emissions damages).[24] Under an international cap-and-trade system, marginal abatement costs are equated across different regions at a point in time if the international regime fully integrates efficient domestic allowance-trading markets. Frictionless borrowing and banking provisions help to equate marginal abatement costs in the current period with those expected in future periods. Under either the tax or allowance system, promoting dynamic cost-effectiveness requires that policies are set in advance over a long time horizon. If policy commitment periods are short, there is the danger that policy stringency will significantly diverge across different commitment periods, causing marginal abatement costs to differ across time. Moreover, a stable, long-term policy framework will help firms make efficient decisions with regard to major R&D or technology investments with long-run payoffs. Finally, a cost-effective agreement can promote (a) broader participation, by limiting the downside risks of noncompliance, and (b) deeper participation, by facilitating more aggressive policy goals in the future.

B. Equity

Usually, an equitable agreement among member countries means that more advanced, wealthier members bear a relatively greater cost burden than less developed, poorer nations. The burden of emissions abatement costs is likely to differ dramatically across regions under an internationally harmonized CO_2 price. In fact, as suggested by Table 2, emerging and developing countries, especially China, would probably bear a disproportionately larger cost than the United States and Western Europe, given the higher CO_2-to-GDP intensities in the former countries.

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[24] Ideally, one would like all agents to face the same unified emissions price; however, because of distortions in foreign exchange markets—such as tariffs on trade, licensing, official intervention, and so on—a single rate defined, say, in U.S. dollars may translate into different rates in different countries.

Table 2. Projected Emissions of CO_2 from Fossil Fuels as a Proportion of Real GDP

	Year				
Country	2002	2101	2020	2030	2040
United States	0.55	0.51	0.47	0.45	0.43
Japan	0.30	0.28	0.28	0.27	0.26
Eastern Europe	0.85	0.77	0.69	0.63	0.58
Western Europe	0.37	0.35	0.31	0.29	0.26
Industrial (Annex 1) countries	0.51	0.47	0.43	0.40	0.38
China	3.11	2.48	2.69	2.72	2.72
Other developing and emerging economies	0.87	0.75	0.71	0.70	0.69
OPEC economies	1.82	1.50	1.36	1.34	1.31
Non-Annex 1 economies	1.29	1.12	1.14	1.12	1.08
World	0.67	0.61	0.63	0.63	0.63

Source: International Monetary Fund (2008), Table 4.5.

Notes: The ratios refer to metric tons of CO_2 per thousand 2000 US$ using market exchange rates. Annex I refers to the group of 40 industrial countries that were signatories to the 1997 Kyoto Protocol to control GHG emissions. Non-Annex I countries refers to all other developing and industrializing nations.

To preserve the cost-effectiveness criterion, equity concerns would ideally be addressed through inter-country side payments or other compensation rather than by allowing policy stringency, and hence marginal abatement costs, to differ across countries. Under a CO_2 tax system, a portion of the revenues raised in wealthier nations might be redistributed to the relatively poor countries through some agreed upon formula that accounts for measures of per capita income, emissions intensities, and perhaps historical contributions to atmospheric GHG accumulations. An analog to direct side payments exists under the cap-and-trade approach, where wealthier countries take on more stringent emissions caps but can exceed these targets by purchasing emissions allowances from poorer countries with relatively lax targets.

C. Broad Country Participation

Obviously, the more countries participate, the more effective the agreement will be in reducing global emissions. Moreover, broad participation reduces the risk of emissions leakage resulting from the relocation of energy-intensive firms within the covered region to countries with no climate policy. The breadth of participation reflects important ex ante and ex post policy decisions.

The first, ex ante, dimension focuses on the number of countries joining the climate policy coalition. Presumably, these countries value the benefits of participation—and of doing something about climate change—more than their burden of costs, whereas those that do not initially participate hold the opposite valuation. Enticing new countries into the agreement over time may again require direct side payments or emissions targets that are initially less onerous. More generally, some countries may remain outside of the formal emissions mitigation agreement but be included in a looser, informal group with more ad hoc incentives for emissions mitigation. For example, some of the revenues from an international CO_2 tax (or from allowance auctions) could finance technology transfer to developing countries.

The second, ex post, dimension is the possibility that individual countries in the agreement will not comply with their obligations or that they may even pull out of the agreement altogether. To deter this may require penalties for noncompliance. For example, countries make an up-front deposit into a fund during the first phase of the policy period (perhaps out of revenues from CO_2 taxes or allowance auctions) and the fund returns the proceeds, with interest, at the end of the policy period, but only to those countries remaining in the agreement. Others have suggested the use of trade sanctions to penalize noncomplying and nonparticipating countries (Nordhaus 1998; Aldy et al. 2001).

D. Reaching Agreement on Taxes or Targets

In a Kyoto-like system, countries have to agree on a set of *national* emissions targets. Initially, these targets can be set relative to actual emissions in a recent reference year; the Kyoto Protocol stipulates 1990 as its reference year. This focus on targets as a function of a historic reference year presents problems for comparing effort and burdens across countries that may experience very different baseline (no new policy) emissions growth rates. Thus, reducing emissions 7 percent below 1990 levels between 2008 and 2012, as the Kyoto Protocol would have required the United States to do had it not withdrawn from the treaty, would have been quite costly, as emissions have grown rapidly since 1990. Similar targets for the United Kingdom and Germany are much less onerous because their emissions declined in the 1990s with the closure of uneconomic coal mines and manufacturing facilities.

Under a tax-based regime, only one variable must be negotiated—the tax rate on CO_2 that countries should impose (along with a rule for tightening it over time). This precludes countries from haggling over country-level targets endemic to a Kyoto-style approach. Of course, if some countries decide not to participate in a harmonized CO_2 tax regime, then they are implicitly imposing a different (zero) tax on their sources of GHG emissions. Explicit transfers (as discussed above) or issue linkage—such as the provision of benefits through trade or development policy agendas—may be necessary to discourage developing countries from advocating for differential tax rates.

E. Institutional Capability in Developing and Industrializing Nations

Variability in baseline emissions also reflects substantial uncertainty in forecasting emissions. Many developing countries lack the capacity to estimate future emissions to assess the implicit stringency of quantitative targets. This motivates the primary developing country objection that emissions caps could constrain economic growth. Even if developing countries could take on quantitative caps, implementing them through a domestic cap-and-trade system may not be feasible. Few developing countries have sufficiently strong environmental ministries to design a cap-and-trade regime. Moreover, weak and less than fully independent judicial institutions raise questions about the enforcement of allowances as property rights. The prospect of free allowance allocations in nations with limited or mixed experiences with privatization also suggests that the tax alternative is superior. From an institutional perspective, much more powerful finance ministries could administer a carbon tax. In some countries, the finance ministry could simply integrate the carbon tax with existing taxes on fossil fuel purchasers. This approach would also take advantage of existing monitoring of energy production, imports, exports, and consumption. Some finance ministries in developing countries may advocate for CO_2 taxes as a new source of badly need revenue (Cooper 2007).

Employing a policy (a CO_2 tax) instead of a goal (a quantitative emissions target) may also be a more appropriate way to move forward with country-level commitments. National governments should commit to what they can directly control. Firms and individuals undertake activities that emit GHGs; governments are responsible for a small share of emissions. Focusing on policy actions may provide for a more credible negotiation than emissions goals that some countries may not know how to attain.

F. Verification

The main drawback of the tax-based approach at the international level is that it could be undermined by “fiscal cushioning:” the reduction of other taxes borne by sources of GHGs to partly offset the burden of a CO_2 tax (Wiener 1999). In some cases, offsetting reductions in other energy taxes are transparent (e.g., a reduction in a gasoline tax); in other cases, they are not (e.g., complex tax loopholes for expensing of capital or technology investments).[25] The same problem does not apply under emissions allowance systems because countries still must meet their national emissions quotas, regardless or whether they introduce compensatory measures for energy.

A possible response to the risk of fiscal cushioning is to develop a broader measure of a country's effective CO_2 tax, accounting for preexisting energy taxes or subsidies. For example, the 40-cent-per-gallon gasoline tax in the United States (on average across the states) is equivalent to a \$45 tax per ton on CO_2 from the automotive sector, or about \$9 per ton of CO_2 for nationwide emissions. Similarly, estimated government revenues forgone from the favorable tax treatment of energy industries could be expressed per ton of CO_2. In principle, all countries might be pressured or required to increase this broader CO_2 tax at the same rate over time. Therefore, any reductions in other energy taxes would require an offset through a higher formal tax on CO_2.

This approach, however, raises three problems. First, it is not always easy to measure the magnitude of complex and opaque systems of energy tax preferences, although international inspection of taxing agencies and the accounts of energy companies would help. Second, broader energy taxes might offset externalities. For example, Parry and Small (2005) estimate that gasoline taxes in the United States fall well below (second-best) levels that might be warranted by traffic congestion, accident, and local pollution externalities. Effectively, this means that gasoline is actually subsidized, not taxed. Third, a wide variety of nontax regulations further penalize, or favor, energy sectors, such as price regulation in the power sector and standards for emissions rates and fuel economy on automobiles. In principle, the tax equivalent of these other regulations needs to be quantified, along with the externalities, and then converted into their CO_2 tax or subsidy equivalents to obtain an unbiased measure of overall CO_2 taxes. These procedures would be quite detailed and controversial.

These considerations suggest the need for two kinds of regular, systematic country reviews. The first type of review would assess whether governments undertake explicit (by changing other tax laws) or implicit (by changing tax subsidies and other regulations) fiscal

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[25] Sweden reduced some of its energy taxes on the most energy-intensive industries when it implemented its carbon tax (Daugbjerg and Pedersen 2004).

cushioning for various sources subject to the CO_2 tax policy. The second type of review would evaluate progress on mitigating emissions, compare efforts across countries, and assess the adequacy of the aggregate effort in combating climate change. These evaluations should be conducted by an independent, international institution, akin to the International Monetary Fund's Article IV consultations and the OECD's annual review of member countries' economic policies (Aldy and Stavins 2007b). Although the reviews may not be sufficient on their own to deter fiscal cushioning, the spotlight on such efforts could draw condemnation from other countries. The pressure from other countries could establish a norm against fiscal cushioning and promote broad, if occasionally incomplete, participation.

V. Concluding Remarks

The success of domestic and international efforts to slow global climate change will depend on how policies meet key criteria, such as keeping down overall policy costs, satisfying distributional objectives, addressing economic variability and disruptions, providing incentives for clean technology development, and facilitating policy coordination and verification among countries. In principle, revenue-neutral CO_2 taxes appear to have a number of advantages over cap-and-trade systems, but the devil lies in the details of the implementation. At the domestic level, an appropriately designed cap-and-trade system—with allowance auctions and smart revenue recycling as well as mechanisms to contain costs, such as a safety valve or banking and borrowing—could mimic many of the benefits of a CO_2 tax. Even so, at the international level, a CO_2 tax might be more effective at promoting broad country participation, especially among developing countries with limited institutions for implementing a new permit-trading system.

Cap-and-trade systems that emerge in practice may also contain serious design flaws. For example, although the European Union's Emission Trading Scheme will transition to nearly full allowance auctions, it is not yet clear whether all European Union governments will use the revenues productively. And although the policy now permits full allowance banking, it still prohibits allowance borrowing across commitment periods; in the near term, this leaves it exposed to the risks of large disruptions, for example, from fuel price shocks. If such a disruption occurs, that could undermine popular support for future, progressive tightening of the emissions cap and for the introduction of similar schemes in other countries. Until allowance systems are well designed and have proven to stand the test of time, the revenue-neutral CO_2 tax remains an attractive alternative, and possibly the more likely policy to facilitate the durable and substantial agreement needed to seriously slow global warming over the coming decades.

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