Market Mechanisms and Incentives: Applications to Environmental Policy

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Resources for the Future
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Market Mechanisms and Incentives: Applications to Environmental Policy

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1616 P Street, NW, Washington, DC 20036
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October 17th – 18th, 2006

October 17, 2006: Market Mechanisms in Environmental Policy

8:00 a.m. – 8:45 a.m. **Registration**

8:45 a.m. – 11:45 a.m. **Session I: Brownfields and Land Issues**
Session Moderator: **Robin Jenkins**, EPA, National Center for Environmental Economics

8:45 a.m. – 9:00 a.m. Introductory Remarks: **Sven-Erik Kaiser**, EPA, Office of Brownfields Cleanup and Redevelopment

9:00 a.m. – 9:30 a.m. Environmental Liability and Redevelopment of Old Industrial Land
Hilary Sigman, Rutgers University

9:30 a.m. – 10:00 a.m. Incentives for Brownfield Redevelopment: Model and Simulation
Peter Schwarz and **Alex Hanning**, University of North Carolina at Charlotte

10:00 a.m. – 10:15 a.m. **Break**

10:15 a.m. – 10:45 a.m. Brownfield Redevelopment Under the Threat of Bankruptcy
Joel Corona, EPA, Office of Water, and **Kathleen Segerson**, University of Connecticut

10:45 a.m. – 11:00 a.m. Discussant: **David Simpson**, EPA, National Center for Environmental Economics

11:00 a.m. – 11:15 a.m. Discussant: **Anna Alberini**, University of Maryland

11:15 a.m. – 11:45 a.m. Questions and Discussion

11:45 a.m. – 12:45 p.m. **Lunch**

12:45 p.m. – 2:45 p.m. **Session II: New Designs for Incentive-Based Mechanisms for Controlling Air Pollution**
Session Moderator: **Will Wheeler**, EPA, National Center for Economic Research

12:45 p.m. – 1:15 p.m. Dynamic Adjustment to Incentive-Based Environmental Policy To Improve Efficiency and Performance
Dallas Burtraw, Danny Kahn, and Karen Palmer, Resources for the Future

	1:15 p.m. – 1:45 p.m.	Output-Based Allocation of Emissions Permits for Mitigating Tax and Trade Interactions **Carolyn Fischer**, Resources for the Future
	1:45 p.m. – 2:00 p.m.	Discussant: **Ann Wolverton**, EPA, National Center for Environmental Economics
	2:00 p.m. – 2:15 p.m.	Discussant: **Arik Levinson**, Georgetown University
	2:15 p.m. – 2:45 p.m.	Questions and Discussion
2:45 p.m. – 3:00 p.m.	**Break**	
3:00 p.m. – 5:30 p.m.	**Session III: Mobile Sources** Session Moderator: **Elizabeth Kopits**, EPA, National Center for Environmental Economics	
	3:00 p.m. – 3:30 p.m.	Tradable Fuel Economy Credits: Competition and Oligopoly **Jonathan Rubin**, University of Maine; **Paul Leiby**, Environmental Sciences Division, Oak Ridge National Laboratory; and **David Greene**, Oak Ridge National Laboratory
	3:30 p.m. – 4:00 p.m.	Do Eco-Communication Strategies Reduce Energy Use and Emissions from Light Duty Vehicles? **Mario Teisl**, **Jonathan Rubin**, and **Caroline L. Noblet**, University of Maine
	4:00 p.m. – 4:30 p.m.	Vehicle Choices, Miles Driven, and Pollution Policies **Don Fullerton**, **Ye Feng**, and **Li Gan**, University of Texas at Austin
	4:30 p.m. – 4:45 p.m.	Discussant: **Ed Coe**, EPA, Office of Transportation and Air Quality
	4:45 p.m. – 5:00 p.m.	Discussant: **Winston Harrington**, Resources for the Future
	5:00 p.m. – 5:30 p.m.	Questions and Discussion
5:30 p.m.	**Adjournment**	

October 18, 2006:

8:45 a.m. – 9:15 a.m.	**Registration**	
9:15 a.m. – 12:20 p.m.	**Session IV: Air Issues** Session Moderator: **Elaine Frey**, EPA, National Center for Environmental Economics	
	9:15 a.m. – 9:45 a.m.	Testing for Dynamic Efficiency of the Sulfur Dioxide Allowance Market **Gloria Helfand**, **Michael Moore**, and **Yimin Liu**, University of Michigan
	9:45 a.m. – 10:05 a.m.	When To Pollute, When To Abate: Evidence on Intertemporal Use of Pollution Permits in the Los Angeles NOx Market **Michael Moore** and **Stephen P. Holland**, University of Michigan

10:05 a.m. – 10:20 a.m.	**Break**	
	10:20 a.m. – 10:50 a.m.	A Spatial Analysis of the Consequences of the SO_2 Trading Program **Ron Shadbegian**, University of Massachusetts at Dartmouth; Wayne Gray, Clark University; and Cynthia Morgan, EPA
	10:50 a.m. – 11:20 a.m.	Emissions Trading, Electricity Industry Restructuring, and Investment in Pollution Abatement **Meredith Fowlie**, University of Michigan
	11:20 a.m. – 11:35 a.m.	Discussant: **Sam Napolitano**, EPA, Clean Air Markets Division
	11:35 a.m. – 11:50 a.m.	Discussant: **Nat Keohane**, Yale University
	11:50 a.m. – 12:20 p.m.	Questions and Discussion
12:20 p.m. – 1:30 p.m.	**Lunch**	
1:30 p.m. – 4:35 p.m.	**Session V: Water Issues** Session Moderator: **Cynthia Morgan**, EPA, National Center for Environmental Economics	
	1:30 p.m. – 2:00 p.m.	An Experimental Exploration of Voluntary Mechanisms to Reduce Non-Point Source Water Pollution With a Background Threat of Regulation Jordan Suter, Cornell University, Kathleen Segerson, University of Connecticut, Christian Vossler, University of Tennessee, and Greg Poe, Cornell University
	2:00 p.m. – 2:30 p.m.	Choice Experiments to Assess Farmers' Willingness to Participate in a Water Quality Trading Market **Jeff Peterson**, Washington State University, and Sean Fox, John Leatherman, and Craig Smith, Kansas State University
2:30 p.m. – 2:45 p.m.	**Break**	
	2:45 p.m. – 3:15 p.m.	Incorporating Wetlands in Water Quality Trading Programs: Economic and Ecological Considerations **Hale Thurston** and Matthew Heberling, EPA, National Risk Management Research Laboratory, Cincinnati, Ohio
	3:15 p.m. – 3:35 p.m.	Designing Incentives for Private Maintenance and Restoration of Coastal Wetlands **Richard Kazmierczak** and **Walter Keithly**, Louisiana State University at Baton Rouge
	3:35 p.m. – 3:50 p.m.	Discussant: **Marc Ribaudo**, USDA, Economic Research Service
	3:50 p.m. – 4:05 p.m.	Discussant: **Jim Shortle**, Pennsylvania State University
	4:05 p.m. – 4:35 p.m.	Questions and Discussions
4:35 p.m. – 4:45 p.m.	**Final Remarks**	

4:45 p.m. **Adjournment**

Dynamic Adjustment to Incentive-Based Policy to Improve Efficiency and Performance

Dallas Burtraw, Danny Kahn and Karen Palmer
Resources for the Future

November 29, 2006

<< Work in Progress – Comments Welcome >>

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Dynamic Adjustment to Incentive-Based Policy to Improve Efficiency and Performance

Dallas Burtraw, Danny Kahn and Karen Palmer

Abstract

The issue of how to set policy in the presence of uncertainty has been central in debates over climate policy, where meaningful efforts to control emissions could prove much more costly than prior regulatory efforts to limit emissions of air pollution. Concern about costs has motivated the proposal for a cap and trade program for carbon dioxide, with a provision called a “safety valve” that would mitigate against spikes in the cost of emission reductions by introducing additional emission allowances into the market when marginal costs rise above the specified allowance price level.

We find two significant problems with this approach, both stemming from the asymmetry of an instrument that mitigates *only* against a price *increase*. One is that the most important examples of price volatility in cap and trade programs have occurred not when prices spiked, but instead when allowance prices fell below their expected values. For example, in the case of SO_2 emission trading, the inability of the trading program to adjust to the fall in allowance prices led to welfare losses of between \$1.5 and \$8 billion dollars per year, measured against congressional intent. A second problem is that a single-sided safety valve may affect the behavior of investors with unintended consequences. Using a Taylor series expansion around the mid case for uncertain future natural gas prices, we measure the distribution of key variables of interest in a detailed electricity market model, where we show that a high-side safety valve can be expected to increase emissions and decrease investment in nonemitting technologies, relative to the absence of a safety valve altogether.

A symmetric safety valve is a price stabilization policy that addresses both unanticipated spikes or drops in the allowance price. When allowance price falls below the safety valve floor, the symmetric safety valve contracts the number of allowances issued in the market. In simulation analysis with uncertain natural gas prices, the symmetric safety valve returns the expected value for these and other key parameters to near their levels in the absence of a safety valve. In addition, although a high-side safety valve improves welfare, a symmetric safety valve improves welfare even further. In summary, we find a symmetric safety valve can improve the performance of allowance trading programs, improve welfare, and may help overcome political objections from environmental advocates who have opposed the use of a safety valve.

Key Words: emission allowance trading, climate change, market-based policies

JEL Classification Numbers: Q4, L94, L5

Dynamic Adjustment to Incentive-Based Policy to Improve Efficiency and Performance

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Dynamic Adjustment to Incentive-Based Policy to Improve Efficiency and Performance

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1. Introduction

Policymakers advance economic efficiency when they set policy goals at levels that equate the marginal costs of additional pollution controls with the marginal benefits of improvements in environmental quality and when they employ incentive-based approaches, such as tradable permits or taxes, to achieve these goals in a least cost manner. When attempting to set goals, policymakers face a great deal of uncertainty about the costs and benefits to society of achieving a particular goal and, in particular, how those costs and benefits are likely to change over time. The presence of uncertainty about both the costs and benefits of regulation also effects on the choice of policy instruments (Weitzman 1974, Roberts and Spence 1978, Pizer 2002).

The issue of how to set policy in the presence of uncertainty has been particularly salient in debates over climate policy, where meaningful efforts to control emissions could prove much more costly than prior regulatory efforts to limit emissions of air pollution. Both the costs and benefits of controlling emissions of greenhouse gases are highly uncertain. One proposal that helps to neutralize this potential would be to include in a carbon cap and trade program a “safety valve” that serves as a ceiling on the price of carbon emission allowances by increasing the provision of emission allowances in the market (Pizer 2002; Kopp et al. 2002). This proposal has found favor with some federal policy makers in the United States and is incorporated in the climate policy section of the comprehensive energy policy advanced by the National Center for Energy Policy in 2004 and later incorporated into legislative language by Senator Bingaman (D-NM), although not yet formally introduced in the Senate. The safety valve cap on allowance prices is also a feature of a climate cap and trade legislative proposal introduced in the House of Representatives by Representatives Udall (D-NM) and Petri (R-WI). A safety valve provision also was incorporated in the proposed Clear Skies Act that would have imposed national caps on emissions of SO_2, NO_x and mercury from electricity generators.

To date most advocates of the safety valve approach focus exclusively on the situation where realized costs of reducing pollution turn out to be higher than expected and thus the original emissions cap is no longer efficient. However, evidence is that *ex post* actual costs of government regulation are often lower than *ex ante* expected costs (Harrington et al. 2000). In many cases, total costs turn out to be lower than expected because baseline emission levels were overestimated and the emissions reductions necessary to achieve a target level end up being less than originally anticipated. Thus since total costs and aggregate reductions tend to be overestimated, the *ex ante* estimates of unit costs (e.g. cost per ton of emissions reduced) tend to be more consistent with *ex post* experience than do estimates of total costs. However, in virtually every case when an incentive form of regulation like an emissions cap and trade approach is used, unit costs have been overestimated prior to the regulation taking effect (Harrington et al. 2000). Indeed, the economic benefits of insuring against the prospect of costs that are *lower* than expected appear at least as important as the benefits of insuring against costs that are *higher* than expected, based on experience with cap and trade programs to date. A key example is the SO_2 caps under Title IV of the 1990 Clean Air Act Amendments. We calculate that a safety valve protecting legislative intent against the prospect that costs would be substantially lower than expected would have improved economic welfare by $1.5 billion to $8.25 billion per year.

The possibility that costs may turn out to be lower than expected or, in a related vein that benefits may turn out to be higher than expected, suggests that the single-sided safety valve that serves to cap the high-side of the allowance price does not provide sufficient insurance against uncertainty. In particular, if costs turn out to be much lower than expected, or if benefits are much higher, the emission cap set forth in a regulation or a piece of legislation could prove dramatically insufficient and also, in many cases, very difficult to change. A regulatory design that could help improve the efficiency of policies in this situation would be a double-sided, or *symmetric* safety valve that sets both a floor and a ceiling on the price of emission allowances.

Using a detailed simulation model of the electricity sector, we find a more pervasive consequence of a single-sided safety valve should be expected. The safety valve affects the expectations of allowance prices, and thereby affects the expectations about the payoff from various investment strategies. Accounting for uncertainty in the future price of natural gas, we find that the single-sided safety valve is likely to reduce the investment in nonemitting technology and increase the expected emissions that obtain under the policy. However, a symmetric safety valve with a floor as well as a ceiling on the price of emission allowances recovers the expected payoff to investments in nonemitting technologies as well as the expected environmental performance of the program. In so doing, it is likely to repair the political coalitions that have been somewhat fractured by the discussion of safety valves to date. A symmetric safety valve would preserve all of the virtue while avoiding the unfortunate unintended consequences of a single-sided approach.

2. Literature Review

The literature addressing the question of instrument choice for environmental policy in the presence of uncertainty about the costs and/or benefits of regulation extends back over thirty years. Early work by Weitzman (1974) identifies conditions under which price instruments would be preferable to quantity instruments and vice versa. In his model, which is the more efficient instrument hinges on the relative slopes of the marginal benefit and marginal cost curves. He shows that quantity instruments are preferred to price instruments if the marginal benefits curve is steeper than the marginal cost curve. In a subsequent paper, Roberts and Spence (1978) analyze a combination of a quantity constraint and a price instrument, which is specified as a licensed target level of emissions, a per unit subsidy for reductions in emissions below the firm's licensed target level and a penalty for emissions above the target where the penalty is weakly greater than the subsidy. Roberts and Spence prove that this hybrid approach yields a lower value of total social costs (defined as the sum of pollution damages and clean-up costs) than would result from using either instrument in isolation. Note that if damages are linear, then the pure tax is optimal, and (1978) finds a similar result when damages are linear. Pizer (2002) uses a computable general equilibrium simulation model to analyze the welfare consequences of using different instruments to reduce CO_2 emissions that contribute to climate change. His work shows that the expected welfare gains from a price approach to climate policy are 5 times higher than expected gains with a pure quantity approach. The optimal hybrid policy of a CO_2 emissions cap coupled with a cap on the price of CO_2 allowances yields slightly higher net social benefits than a tax policy by itself, and also substantially outperforms the pure quantity approach. The hybrid approach outperforms the pure price policy because, in this case, the climate benefits function is slightly convex.

Pizer does not consider a lower bound on the price of allowances and dismisses the use of a floor on allowance prices, implemented in the form of a commitment to buy back allowances once the price falls to the level of the floor, as having adverse dynamic properties as discussed in Chapter 14 of Baumol and Oates (1988). They argue that subsidizing emissions reductions in a competitive industry will typically lead to decreased output at the firm level, but increased output at the industry level and can also lead to higher emissions. They also cite Wenders (1975) who argues that subsidizing emission reductions can reduce incentives for the adoption of a new pollution-reducing innovation if firms anticipate that adopting the new technology will reduce subsidy payments. In both these cases, the assumption is that firms have the property rights to emissions and the government is buying them back. However, the symmetric safety valve need not be implemented as a government buy-back of allowances that were previously distributed for free. For example, if some portion of allowances is being sold in an auction instead of distributed gratis, the low-side safety valve could take the form of a floor on the price of those auctioned allowances. If the willingness to pay for emission allowances were to fall below that floor, less than the allowable quantity of emission allowances should be sold. This is a standard practice in auctions when willingness to pay is uncertain (Burtraw and Palmer, 2006). Also, if compliance periods extend for multiple years and low prices prevail during the early years, allocations in the later years of the compliance period could be reduced, which would lead to higher prices in earlier years if allowance banking is allowed and in effect.

An important insight from the Weitzman (1974) paper, which has typically been ignored in subsequent work, is the role of correlation of benefits and costs in the identification of optimal instruments. Stavins (1996) shows that when benefits and costs are statistically correlated, benefit uncertainty can affect instrument choice and the extent of that effect depends on several parameters. When benefits and costs are positively correlated, a quantity approach to regulation tends to be preferred to a price approach and when the correlation is negative, the tax approach will tend to be preferred. Stavins argues that positive correlation is more likely and that in general correlation in benefits and costs tends to favor emissions caps over emissions taxes. Evans (2006) considers correlation among the cost of control and reduction of various pollutants. He finds that Weitzman's advice regarding the choice of quantity or price instrument does not hold in general, and the efficient choice of instrument for one pollutant will depend on the choice for the other pollutant.

Another strand of the literature looks at the potential for emissions intensity regulation to out perform fixed quantities or prices in the presence of uncertainty. Quirion (2005) finds that with uncertainty about business-as-usual emission levels and about the slope of the marginal cost curve, an absolute cap on emissions produces slightly higher expected welfare than a cap on emissions intensity, but a price instrument yields substantially higher expected welfare than an intensity cap. Pizer (2005) suggests that indexing emissions targets to a measure of economic growth is a good approach for dealing with economic growth and unexpected changes in economic fortunes. Pizer and Newell (2006) analyze the use of indexed regulation for climate policies and identify conditions (related to the first and second moments of the index and the ex post optimal quantity level of the emissions cap) under which indexing will improve welfare as compared to both fixed quantities and fixed emissions taxes.

A safety valve has obvious relevance with respect to the ability to respond to changes over time, and therefore has some relation to the opportunity to bank emission allowances. The relationship between emissions banking and a safety valve is little explored in the literature.

Jacoby and Ellerman (2004) suggest that banking will provide less protection from upside cost shocks than would a safety valve, particularly during the early years of a policy when no bank has yet accumulated for firms to draw on (assuming borrowing from the future is prohibited). However, they also point out that banking can provide greater price support in the case of lower than average cost, because the safety valve proposals usually do not include a price floor on allowances. Banking provides a way to capitalize on a short run decline in marginal abatement cost by enabling extra emission reductions in that period that can be banked for use in later periods when costs may be higher. However, if the decline in cost is long-term in nature then the price will fall in every period and banking will provide little price support.

3. The Single-Sided Safety Valve

The flexibility given to individual firms that is inherent in a cap and trade program has as its *raison d'être* the underlying variability in costs of the environmental policy at individual facilities. To other firms and the government, the variability in costs appears like uncertainty. Investors would be expected to take into account the distribution of potential outcomes when, so the underlying variability along with uncertainty about various factor prices and technical issues may be thought of as a fundamental characteristic of the problem.

We can begin to see the incentive effects of a policy feature such as a safety valve on investment behavior by considering the case of simple asymmetric information, wherein the investor has perfect foresight but the regulator has to make a decision in the absence of that information, perhaps before the information is revealed. For example, Title IV of the Clean Air Act Amendments regulating sulfur dioxide (SO_2) passed Congress in 1990 but the first phase of the program did not take effect until 1995, and the second took effect in 2000. In 1990 the delivered price of natural gas for electric utilities was about \$3.15/kcf but by 1999 it had fallen to \$2.89/kcf (2004\$). Similarly, the average price for low sulfur subbituminous coal fell from about \$12.81/ton in 1990 to \$7.56/ton in 1999, while the consumption of low sulfur coal grew tremendously (EIA 2005, Tables 6.8 and 7.8). Investment decisions to comply with the legislation crafted by Congress in 1990 continued to take shape more than a decade later.

The safety valve has been suggested as a mechanism to insure against outcomes that differ widely from anticipated costs under a cap and trade program. For example, if price of an important factor of production were to rise higher than expected, potentially leading to unexpected costs of pollution control, the safety valve mechanism could issue additional emission allowances at a specified price thus effectively assuring that the marginal cost of pollution control could not rise above that price.

To illustrate the safety valve we conjecture a potential carbon dioxide (CO_2) emission reduction policy. We conjecture marginal benefits of emission reductions to be a known parameter and assume the regulator sets a target where marginal benefits equal expected but uncertain marginal cost. We evaluate the important case of natural gas price uncertainty using RFF's detailed simulation model of the electricity sector. The model divides the nation into 20 regions, 9 of which are assumed to yield electricity prices based on market prices, and the rest are assumed to be under cost of service regulation. The model includes the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR) policies for NO_x, SO_2, and Hg emissions. We assume a discount rate of 8%, with 2030 as the forecast horizon year.[1]

The results for this example are illustrated in Figure A, where the horizontal axis represents the aggregate emissions of CO_2 from the electricity sector in 2020. We characterize the mid value for future natural gas prices to be $6.31/mmBtu under the policy. The central point in the figure is a quantity target (E^*) of 2,423 million tons where, under the mid value for natural gas price, we expect a marginal cost (P^*) of $31.15 per ton. We assume this is exactly equal to the marginal benefit, which is a known parameter. Under the assumption that marginal benefits are constant, the same outcome with respect to aggregate emissions could be achieved by setting an emission fee equal to P^*, which would result in an emissions level E^*.

<Insert **Figure A**. Illustration of the safety valve.>

The downward sloped line that lies above the expected permit price in Figure A illustrates a realization for natural gas prices in which prices are higher than expected, and equal to $10.16/mmBtu. This leads the cost of achieving emission reductions to be higher than in the mid case because shifting from coal-fired to gas-fired generation is an important way that emission reductions are achieved. For the high gas price case the marginal cost of achieving the emission target E^* increases to P^h = $50.55/ton. Since marginal benefits are assumed constant and equal to $P^* < P^h$, there is a welfare loss equal to the large shaded triangle because the quantity of emissions are too low given the high cost of emission reductions in the high gas case.

[1] Further detail on the model can be found in Paul and Burtraw (2002).

This example illustrates the way that a single-sided safety valve can improve welfare. Were there a safety valve in place, say at a level equal to the average of the mid and high allowance price outcomes, e.g. P^{HSV} = $ 41/ton, it would cap the level at which marginal costs could rise by issuing additional emission allowances, leading to emissions of 2,568 million tons. Compared to the target where marginal benefit equals marginal cost (E^*, P^*), there would still be a welfare loss at P^{HSV} indicated by the smaller cross-hatched triangle, but this welfare cost would be less than from the strict quantity instrument without the safety valve.

4. The Symmetric Safety Valve

Were the safety valve to apply only when marginal costs are higher than expected the emission target would not respond if natural gas price to turns out to be lower than expected. The lower line segment in Figure A illustrates this outcome with a natural gas price in 2020 equal to $4.42/mmBtu, where the marginal cost of achieving the emission target E^* decreases to P^L = $17.57/ton. The welfare consequences of the drop in natural gas price can be just as great as when gas price is higher than expected due to the difference between marginal benefits and marginal costs. Since marginal benefits are assumed constant and equal to P^* there is a welfare cost analogous to the large shaded triangle in the previous example, but in this case the loss is due to the fact that from an efficiency perspective the quantity of emissions is too high given the low cost of emission reductions.

A low-side safety valve could correct for the unexpected decline in compliance cost. Were there a safety valve level at a level that was the average of the low and mid allowance price outcomes, P^{LSV} = $24.31/ton, it would cap the extent to which marginal costs could fall by reducing the number of allowances provided to the market in the current or future periods. A reduction in emissions to E^{LSV} = 2,257 million tons would be achieved. There would still be a welfare cost compared to the efficient outcome ex post, but the cost would be less than under the strict quantity instrument without the safety valve.

There has been little attention given to how a safety valve would function. In the case of a high-side safety valve, advocates have suggested that the regulator could issue additional allowances at the safety valve price level through direct sale, or potentially through free allocation. The low-side safety valve has the same structure. If allowances fall were to the level of the floor, the regulator would reduce the provision of allowances in future periods. An example of this approach is embodied in the Clean Air Interstate Rule (CAIR) where the allowable quantity of future emissions changes the value (ton of emissions per allowance) of future allowances without changing the quantity of the allowances. If the program includes interperiod banking, this reduction in the number of allowances issued in the future will lead to an increase in the price of allowances in future and in the current period, as occurred with the promulgation of CAIR.

An even more direct way to implement the low-side safety valve would be through adjustments in an auction, were an auction to be used for to initially distribute a portion of the allowances. In this case the safety valve would directly resemble a reservation price in the auction, which is a common feature in auctions including previous auctions for the distribution of emission allowances. When the safety valve policy combines a high-side and a low-side safety valve, we refer to it as a symmetric safety valve.

5. Historical Experience

Historically, the failure to have a safety valve on the low side in the event that compliance costs are lower than expected has had larger consequences than the failure of a safety valve on the high side. The only important example of unexpected outcomes within a cap and trade program that may have been remedied by a safety valve on the high side has been the RECLAIM program in southern California, where prices skyrocketed in 2000 due to unexpected demand for emission allowances reflecting very high marginal cost of compliance, which led to suspension of trading in the program in 2001. In that program, however, emission allowance banking also could have helped remedy the market disruption.

In contrast, the most prominent economic failure of any cap and trade program has occurred in the SO_2 program under Title IV – a program generally noted for its many successful aspects. The SO_2 program is credited with success in facilitating the reduction in compliance costs compared to prescriptive regulatory approaches (Carlson et al. 2000; Ellerman et al. 2000), demonstrating on a large scale the effectiveness of an economic approach to pollution control (Stavins 1998; Joskow, Schmalensee and Bailey, 1998), and achieving billions of dollars in environmental and public health benefits.

However, the expensive failing of the SO_2 program has been its inability to adjust to new information. In 1990, at the adoption of Title IV, Portney (1990), the only economist who ventured an opinion about the benefits and costs of the amendments, concluded that the benefits of Title IV about equaled the cost. By the first year of the program's implementation in 1995, it had become clear that the benefits would be an order of magnitude greater than costs (Burtraw et al. 1998). Unfortunately the program was unable to adapt to this new information until the adoption of CAIR, now scheduled to take effect fifteen years after the launch of the program.

Why did the estimates of benefits and costs change so dramatically? First, the anticipated benefits of emission reductions grew tremendously with new information about the damage to human health from fine particulates associated with emissions of SO_2 and NO_x. Second, and more important to this discussion, the estimates of the costs of emission reductions fell sharply, due in large part to the flexibility in compliance options afforded by the program.

The fact that information can change so dramatically and so quickly leads one to ask: To what extent does policy reflect scientific information about both the benefits and costs of regulation? Scientific and economic information is fundamentally uncertain. How policy-making interprets the data, and how the policy system responds when scientific information evolves, is of vital importance. Typically, once regulators reach a decision, it becomes exceedingly difficult to modify that decision (Center for International Studies, 1998). For instance, the Clean Air Act was amended in 1977, again in 1990, and has not been amended further since. Statutory regulation such as Title IV put regulators feet into cement. It is very difficult to change statutory direction given new scientific information.

The policy system could benefit from the use of decision rules that automatically incorporate new information. It is understandable that the policy system would be slow to incorporate new information about the benefits of Title IV, because information about benefits is not readily observable outside of the process of scientific research and peer review, which may take years to achieve general acceptance. However, cap and trade programs are uniquely designed to generate information about costs, in the form of allowance prices, which instantaneously provide a summary statistic of pollution control costs that is widely accessible.

<Insert **Figure B**. Variation in SO_2 prices.>

Before passage of CAIR, which directly influences compliance with the SO_2 trading program, estimates suggested that the expected SO_2 emissions in 2010 were to be about 9.18 million tons (Banzhaf et al. 2004). In 1990 the EPA estimated that the marginal cost of achieving the emission reduction targets in Phase II around the year 2010 would be $718-942/ton (2004$)(ICF 1990). However, as the program unfolded it quickly became apparent that the marginal costs as reflected in the price of emission allowances were dramatically below expectations. Figure B illustrates that the price has been well below $200/ton throughout most of years of the program.

Let us imagine that it was Congressional intent to roughly balance marginal benefits with marginal costs, and that a low-side safety valve had been in place that would reduce the provision of allowances were price to fall below $567/ton, about 33% below the mid-value of the range of expected costs. Banzhaf et al. estimate that an SO_2 allowance price of $567/ton in 2010 would yield total national annual emissions of 7.1 million tons, about 2.08 million tons less than under Title IV in the baseline (and in the absence of CAIR).

What would have been the value of a low-side safety valve that led to additional emission reductions? Banzhaf et al. use estimates of marginal benefits of $3,968/ton. This is substantially less than those used by the EPA in Regulatory Impact Assessment because Banzhaf et al. use a lower value of statistical life. Using the Banzhaf et al. estimates, the additional annual health benefits from placing a floor on the allowance price would total $8.25 billion in 2010 (2004$). Perhaps Congress could not have expected benefits of this magnitude from a safety valve, because it did not expect benefits to be this large. Alternatively, one could say that if Congress acted to equate marginal benefits and marginal costs then they would value additional emission reductions at an expected value of $718-942 per ton. At this value, the anticipated additional health benefits from the safety valve set 33% below expected marginal cost would be between $1.5 billion to $1.95 billion in 2010. Arguably, the legislative intent of Congress was to capture these benefits, but they did not have the policy tools available at the time to anticipate and flexibly adjust to changes in scientific information. The symmetric safety valve provides such a tool.

6. The Safety Valve Affects Expectations

The model illustrated in Figure A has a fundamentally naïve characterization of behavior because, as illustrated, the regulator makes decisions on the basis of expected values. She does not account for the effect of the safety valve affects expected values. Consequently the imposition of a one-sided safety valve will influence the market equilibrium and affect the decisions of investors, with unintended and potentially negative consequences that could undermine policy goals.[2].

[2] By analogy, the provision of insurance affects the behavior of investors because the insurance changes the expectations over potential pay-offs. Here we find something similar – investors can be expected to respond to the safety valve, which leads to a different market equilibrium.

We simplify the multi-period problem into an instantaneous present value calculation. Considering the profit function for a single firm that offers nonemitting electricity generation:

$$\pi = q \bullet P\left(Q, P_A\right) - C\left(q\right) \tag{1}$$

where q is the quantity produced by the potential investment, Q is the aggregate quantity in the market and P_A is price of allowances. Cost is a function of quantity of the production. The price of emission allowances is not included because the facility is nonemitting. We assume that the electricity price function and the cost function are increasing in their arguments.

The firm maximizes profits by choosing quantity (q). Under the assumption that the facility's output is too small to make an impact on the aggregate production and price, then $\frac{\delta P}{\delta q} = 0$ and the firm maximizes profits by choosing q such that marginal revenues equal marginal costs:

$$P\left(Q, P_A\right) = \frac{\delta C}{\delta q} \tag{2}$$

In general we expect the aggregate quantity and price of allowances to be uncertain, so that $Q = \tilde{Q}$ and $P_A = \tilde{P}_A$ (where the tilde represents uncertain variables), which cause the product price to be uncertain ($P = \tilde{P}$). Assuming the firm is risk neutral, the profit maximization condition would require the firm to equate expected marginal revenue with marginal cost: $\mathrm{E}\left(P\right) = \frac{\delta C}{\delta q}$. We will note the potential distribution f of allowance prices stretching from zero, bounded at the minimum, to infinity $\tilde{P}_A \sim f\left(0, \infty\right)$, which along with the distribution of potential aggregate generation determine the expected electricity price.

The high-side safety valve intentionally alters the distribution of the potential allowance price, so that the price cannot rise above the safety valve level (SV). If we naively ignore the interaction of the allowance price and the investment decisions of other firms and consider only the role of the safety valve on allowance price when the decisions of other firms are held constant, e.g. $\left(\frac{\delta Q}{\delta P_A}\right) \cong 0$, then the allowance price with the safety valve has the distribution:

$$\begin{aligned} \tilde{P}_A^{SV} &\sim h\left(0, SV\right) \\ &= f \quad \text{for } P_A \le SV \text{ and} \\ &\quad SV \text{ for } P_A > SV. \end{aligned} \tag{3}$$

Letting F and H be the cumulative distribution functions for $\tilde{P}_A^{SV}$ and $\tilde{P}_A$, then $F \leq H$ over their entire range, and $\tilde{P}_A^{SV}$ will have an expected value that is strictly less than P_A, $\mathrm{E}\left(P_A^{SV}\right) < \mathrm{E}\left(P_A\right)$.

This naïve characterization of the change in the distribution of potential allowance prices is illustrated in Figure C. The top panel illustrates a probability distribution for allowance price with the dotted curve. Allowance price is designated simply by "P" in the absence of a safety valve. The expected value for the allowance price is designated E(P), shown by a dotted line. The addition of the safety valve censors the potential distribution of allowance prices. If the distribution is otherwise unaffected, as described in equation (3), the mean shifts to the left, as indicated by the dashed line $\mathrm{E[Psv]}_{\text{naïve}}$.

<Insert **Figure C.** Illustration of the distribution of allowance prices associated with uncertain gas price outcomes.>

A consequence of the change in the allowance price would be a change in the equilibrium in the electricity market, leading to a lower price under the safety valve, $\mathrm{E}\left(P^{SV}\right) < \mathrm{E}\left(P\right)$. The individual profit maximizing investor described in equation (1) would choose a level of production under the safety valve where:

$$\mathrm{E}\left(P^{SV}\right) = \frac{\delta C}{\delta q^{SV}} < \frac{\delta C}{\delta q} = \mathrm{E}\left(P\right) \tag{4}$$

leading to a reduction in its investment and output, $q^{SV} < q$.

The consequence of the high-side safety valve in this example is to reduce investment in the nonemitting facility. One can conjecture that in the aggregate the policy leads to less investment in renewable technology or low-emitting technology that may suffer a price disadvantage when the external social costs of electricity generation are not included in electricity price. The cap and trade program serves as a mechanism to internalize into investment decisions the social cost of technology choices and "level the playing field," as many observers have suggested. However, the single-sided safety valve would appear to provide an asymmetric influence that would tilt the playing field away from investments in nonemitting sources.

7. The Safety Valve Equilibrium in a Model with Perfect Foresight

The formulation above assumes that the behavior of other investors or actors in the market does not respond to the change in expectations, and that aggregate quantity and characteristic of generation by other parties is unchanged due to the change in allowance price $\left(\frac{\delta\tilde{Q}}{\delta P_A}=0\right)$. However, clearly there would be a response. For instance, one could imagine that a lower allowance price would lead to more fossil generation, which would seem to lower electricity price and reinforce the effect described above. However, the lower allowance price also might increase the emission intensity of generation for any given level of production, which would cause a sort of bounce back in the price of allowances. In addition, whatever the underlying source of uncertainty for allowance price is, it is also likely to affect directly the cost and aggregate quantity of production.

In Figure C the probability density function for potential allowance price in the new equilibrium under the safety valve is illustrated by the solid curve in the top panel, and the solid line illustrates the new expected value of the distribution. The bottom panel illustrates the shift in the cumulative distribution function. We conjecture that the new equilibrium yields an expected value that is between the other two measures that are illustrated. But the equilibrium outcome in a general model is difficult to anticipate without simulation modeling. Therefore we return to that platform. In doing so, we conjecture *a priori* that the high-side safety valve should lead to less investment in nonemitting and low-emitting sources of generation than in the absence of the safety valve, as well as a lower expected allowance price, a lower electricity price and greater expected emissions.

In the simulation we explore underlying uncertainty about natural gas prices in the future. As the central case we adopt EIA (2006) forecasts reported in the *Annual Energy Outlook.* We consider two alternatives, which are labeled high and low gas price cases and incorporate a 30% increase and decrease in gas prices. We assume gas price is normally distributed. High and low prices are picked to represent prices that are one standard deviation away from the mean.

In this modeling exercise we freeze natural gas and coal prices at the assumed forecast values in each year and thus these fuel prices are not allowed to vary with the level of fuel used. We also freeze the level of electricity consumption in order to avoid second best issues in the welfare calculation that are associated with differences between price and marginal cost. For all of the pollution policies emission allowances are allocated to emitters on the basis of historic generation and additional permits are purchased at the safety valve price.

<Insert **Table 1**. Deterministic model with certain foresight.>

The equilibria that are achieved under each scenario are summarized in Table 1. In each case, the model is deterministic and actors behave as though they have certain and perfect foresight – e.g. they know the future path of natural gas prices and respond accordingly. The middle column represents the mid case for gas prices. The first and last columns represent the outcome for low and high gas prices respectively, in the absence of a safety valve. There is little change in CO_2 emissions, but it is interesting to note that low gas prices lead to a modest increase in emissions because there is new gas generation in lieu of new investment in renewables. High gas prices also lead to an increase in emissions, as gas-fired generation falls and there is an increase in coal-fired generation that more than offsets the new investment in renewables. Allowance price ranges widely from a low of $33 under the low gas scenario to a high of $74.Electricity price also ranges widely. Figure D illustrates the change in electricity price relative to the mid case for each simulation year in the model.

<Insert **Figure D**. Variation in electricity prices in the deterministic model with perfect foresight.>

The second column of Table 1 represents the influence of a safety valve on the low side, which we label a symmetric safety valve. The fourth column represents a single-sided safety valve on the high side. On either side, the safety valve has a direct effect on CO_2 emissions, as would be expected because it affects the quantity of emissions directly. As a consequence the variation in other variables such as electricity price and renewable generation is reduced, compared to the absence of the safety valve.

Note also that in either case, the safety valve improves welfare relative. Welfare is calculated as the sum of changes in producer and consumer surplus, plus the change in environmental benefits associated with changes in emissions relative to the emission quantity target, valued at their expected cost of $51 /ton. The change in welfare for each case is measured relative to the mid gas case. The greatest improvement comes from adding a safety valve in the high gas price case. Relative to the mid gas price case, which is normalized to a value of zero, the high gas price case leads to a loss of over $23 billion. The high-side safety valve reduces this loss to about $7 billion because it closes the gap between marginal benefits and marginal costs by allowing an increase in emissions. In the low gas case, welfare improves by over $37 billion, due to lower cost of production. In the low-side safety valve case, welfare improves further to $40 billion by reducing emissions below the emission target, thereby taking advantage of the relatively low marginal cost of abatement.

8. Modeling Uncertainty

The simulation model is deterministic, meaning that it incorporates certain foresight about potentially uncertain variables. Investment decisions are made as though each actor knows for certain the future values of every variable, as well as the decisions of every other actor, so there is no uncertainty taken into account in the model solution. However, although the model is itself deterministic, we can use a collection of model solutions to make a mathematical inference about the outcome of the market equilibrium when investors make decisions taking uncertainty into account.

Using the results from the deterministic model for various realizations of the underlying uncertain parameter, we construct a linearization using the delta approach, which is a variation of a Taylor series expansion. The expected value of a function ϕ of a random variable $\tilde{g}$ with expected value $\overline{g}$ and variance σ_g^2, can be approximated by:

$$\begin{aligned} \mathrm{E}\left[\phi(\tilde{g})\right] &\cong \phi(\overline{g}) + \phi'(\overline{g})\mathrm{E}\left[(\tilde{g}-\overline{g})\right] + \frac{1}{2}\phi''(\overline{g})\mathrm{E}\left[(\tilde{g}-\overline{g})^2\right] \\ &= \phi(\overline{g}) + \frac{1}{2}\phi''(\overline{g})\sigma_g^2 \end{aligned} \tag{5}$$

where ϕ' and ϕ'' ' are first and second derivatives of the function.

The function ϕ can represent a variety of measures that we are interested in including aggregate economic welfare, electricity price, allowance price or the installed nonemitting generation capability. For this experiment, the random variable $\tilde{g}$ is the natural gas price. We consider low, mid and high values of $4.42/mmBtu, $6.31/mmBtu, and $8.21/mmBtu in 2020 (2004$). We assume it is common knowledge that these prices are distributed normally with an expected value of $6.31/MMBtu and a standard deviation of $1.90/MMBtu, so the mid value in this experiment is the mean value of the natural gas price and the low and high values are both one standard deviation from the mean.

<Insert **Table 2.** Delta method approximation of key variables in model with uncertainty.>

The results from this experiment are reported in Table 2, for the case of no safety valve, a high-side (only) safety valve, and a symmetric safety valve. The high-side safety valve leads to the expectation of greater emissions than in the no safety valve case because with some probability the safety valve will be triggered, thereby placing extra allowances on the market. As a consequence the allowance price and electricity price are lower. All variables except welfare are normalized using the no safety valve case as a numeraire (the value is set equal to one). For welfare, the difference between the no safety valve case and the mid case in the deterministic model is normalized as a numeraire because only changes in welfare have economic relevance. A potentially important unintentional result is that the lower expected allowance price leads to lower expected payoffs to investment in renewable technologies. Consequently we see a decline in renewable generation. Here, only a subset of renewable technologies is allowed to change because biomass is held constant. Were biomass also allowed to change one would see even more of an effect on renewable generation.

Many observers have criticized the high-side safety valve because it might undermine the environmental targets of the program, and that is the result we obtain. Emissions are higher and investments in new technology are lower as a result of the safety valve. The reduction in investments initiates a cascade of consequences, as there is less learning as a result of the decline in investment, so the costs of renewable technologies remain above their levels in the absence of the safety valve.

However, the unintended consequences are fully remedied when the safety valve is characterized as a symmetric instrument. In this case, emissions fall back to virtually the same level as in the absence of a safety valve, and renewable investments increase to above their level in the absence of a safety valve. The results for the high-side and symmetric safety valve are compared visually in Figure E. The figure shows that not only do measures of interest to environmental advocates return to their intended levels, but welfare improves even further than in the case with only a high-side safety valve. Also, electricity price and allowance price return to nearly the same level as in the absence of the safety valve.

<Insert **Figure E.** Delta method approximations of outcomes under uncertainty.>

9. Surprise in a Model with Certain but Imperfect Foresight

The delta method could be applied in a different way by assuming a different information structure. In the previous example, the finite differences are calculated using the model with perfect foresight. An alternative would be certain but imperfect foresight; wherein investment decisions made under one set of assumptions could prove imprudent were conditions to change unexpectedly. For example, if gas prices deviate from expectations after investment decisions have been made, then generators could experience large losses in profits and welfare could be negatively affected. Since the safety valve is a policy attempt to mitigate the welfare costs of surprises such as this one, we consider a case where investors' expectations are incorrect, and use these data to calculate finite differences.

The scenario involves a surprise in natural gas prices in 2015. Investors make an investment plan based beginning in the first simulation year in 2010 and based on certain but imperfect foresight about the future path of gas prices. In 2015, investors learn that gas prices are on a different path. Taking existing investments as sunk, investors solve the perfect foresight with the new data. We ran simulation scenarios that include a gas price surprise to determine the effect both a one-sided and symmetric safety valve would have on the expected value of several key variables.

Figure F illustrates the path of electricity prices under the surprise in natural gas prices, compared against the expected price path for prices that was illustrated previously in Figure D. The surprise in 2015 leads to a precipitous change in electricity prices in the absence of a safety valve, especially when natural gas prices rise unexpectedly.

<Insert **Figure F.** Variation in electricity prices in the model with certain but imperfect foresight.>

The surprise in gas prices lead to comparable variations across the different policy scenarios than were obtained in the previous example for most variables. Table 3 illustrates these differences. One outcome that is interesting is the increase in renewable generation in the high gas price case with a high-side safety valve. The reason is that although dedicated biomass does not change in the model, co-fired biomass is allowed to change. The high gas price leads to more coal-fired generation, and with that comes a greater amount of co-fired biomass.

<Insert **Table 3.** Model with certain but imperfect foresight and a gas price surprise in 2015. Results for 2020.>

We apply to delta method to this set of results to replicate the experiment of a first-order approximation to behavior in a model with uncertainty. Table 4 reports these results, and they are illustrated visually in Figure G. Again, the variables of interest return to their approximate levels in the absence of the safety valve. The effect on renewable generation is greater than in the previous example. Also, the welfare contribution of a symmetric safety valve is greater relative to the high-side safety valve.

<Insert **Table 4.** Delta method approximation of key variables in model with certain but imperfect foresight, results for 2020.>

<Insert **Figure G.** Delta method approximations of outcomes in a model with certain but imperfect foresight.

10. Conclusion

Significant attention has been directed to price stabilization measures in emission allowance trading programs. In particular, attention has focused on the introduction of a single-sided safety valve that would mitigate potential price spikes by introducing additional emission allowances into the market when costs rise above the specified “safety valve” level. However, experience with such programs indicates that the most important examples of price volatility to date have occurred when allowance prices fell below their expected values. For example, in the case of SO_2 emission trading, the inability of the trading program to adjust to the fall in allowance prices led to welfare losses of between $1.5 and $8 billion dollars per year.

A second reason to be interested in a price stabilization mechanism when prices fall below expectations is the influence that low prices have on investment. In the absence of a safety valve, investors will take risks given expectations over a distribution of potential payoffs for their investment. A high-side safety valve that prevents spikes in allowance prices will have the unintended consequence of lowering the overall expected allowance price, and as a consequence the overall expected return on an investment in nonemitting technology.

A symmetric safety valve solves both these problems. A symmetric safety valve is a price stabilization policy that works in the case of unanticipated spikes or drops in allowance price. In the case when allowance price falls below the safety valve floor, the safety valve would contract the number of allowances issued in the market. The reduction in the quantity of allowances can be implemented in a variety of ways, but the simplest way may be through a change in the portion of emission allowances that is initially distributed through auction. In fact, good design suggests that an auction should have a reservation price, which is a floor below which the allowances will not be sold. Such a price floor serves directly to implement the low-side safety valve.

We use a linear approximation representing a Taylor series expansion around the mid case to model uncertain natural gas prices in a detailed electricity market model. We show that a high-side safety valve can be expected to increase emissions and decrease investment in nonemitting technologies, relative to the absence of a safety valve. However, the symmetric safety valve returns the expected value for these and other key parameters to the vicinity of their levels in the absence of a safety valve. In addition, although a high-side safety valve improves welfare, a symmetric safety valve improves welfare even further. In summary, we find a symmetric safety valve can improve the performance of allowance trading programs, improve welfare, and may help overcome political objections from environmental advocates who have opposed the use of a safety valve.

Two areas remain to be developed in this analysis. One has to do with a method for determining the breadth of a safety valve around expected marginal costs. When marginal benefits are constant, as in the examples we use, then the most efficient safety valve would be one exactly equal to the value of marginal benefits. In other words, the efficient policy is a tax. However, when marginal benefits are not flat but vary over a range then intuition suggests the efficient safety valve would vary from the expected level of marginal benefits.

A second area to be developed is the relationship between the idea of a safety valve and other approaches to stabilizing prices such as the so-called “circuit breaker.” The circuit breaker approach would anticipate a tightening of an emission cap over time, but modify that path in response to fluctuations in prices. If the price rose above a specified level, the reduction in the emission cap would be delayed. This approach has a strong similarity to a safety valve. In work currently in progress we are developing the analytical similarities of these two approaches.

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Figure A. Illustration of the safety valve.

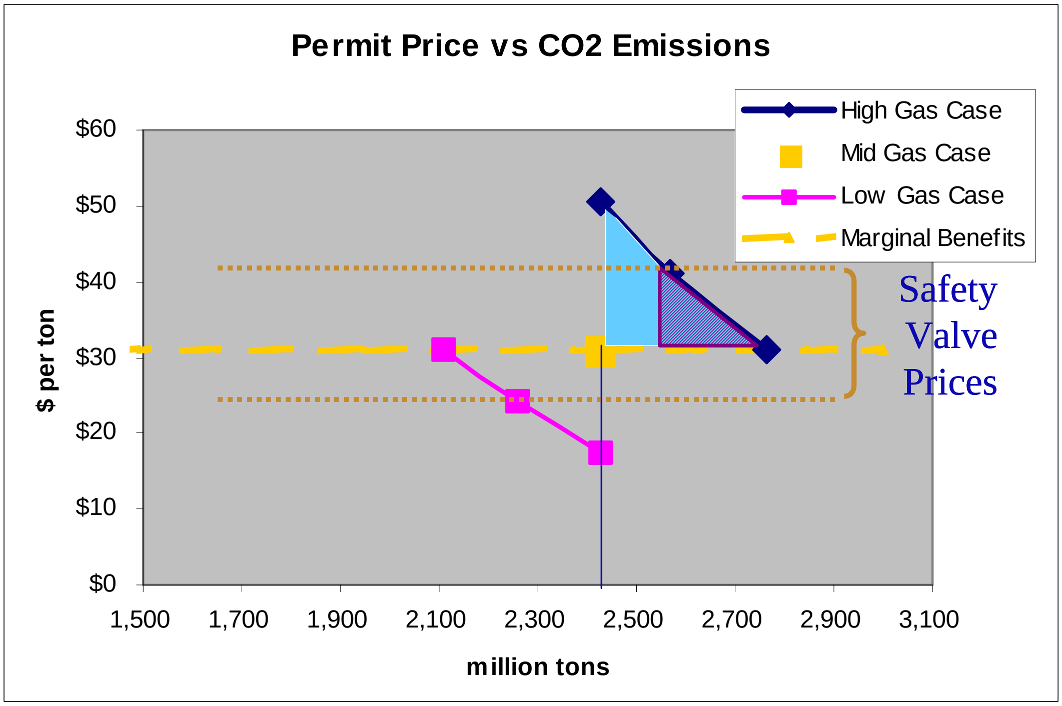

Figure B. Variation in SO_2 Prices

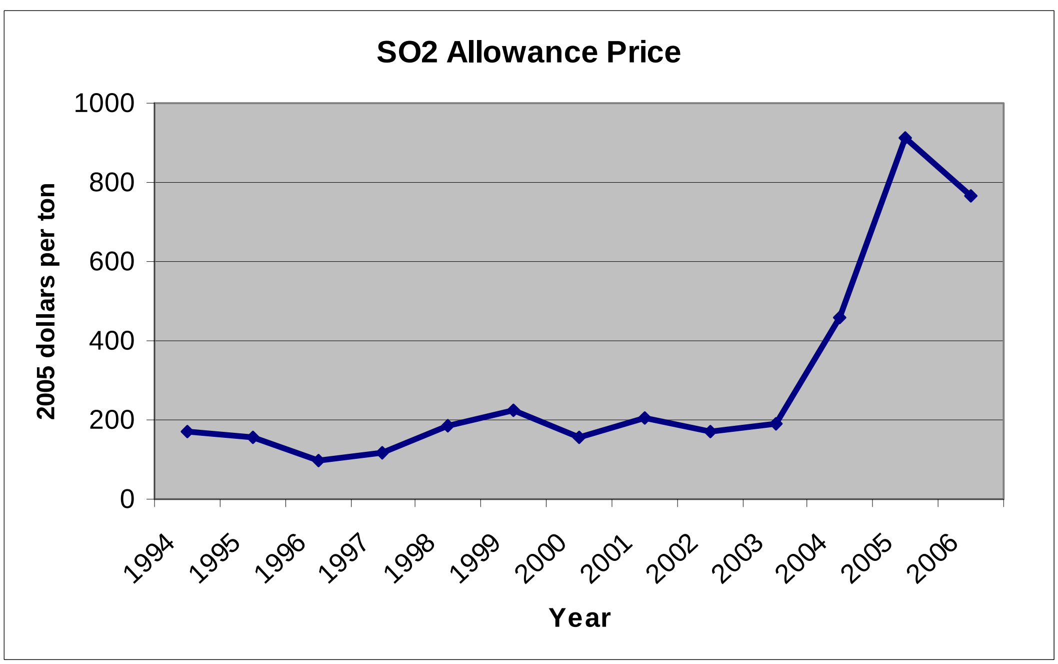

Figure C. Illustration of the distribution of allowance prices associated with uncertain gas price outcomes.

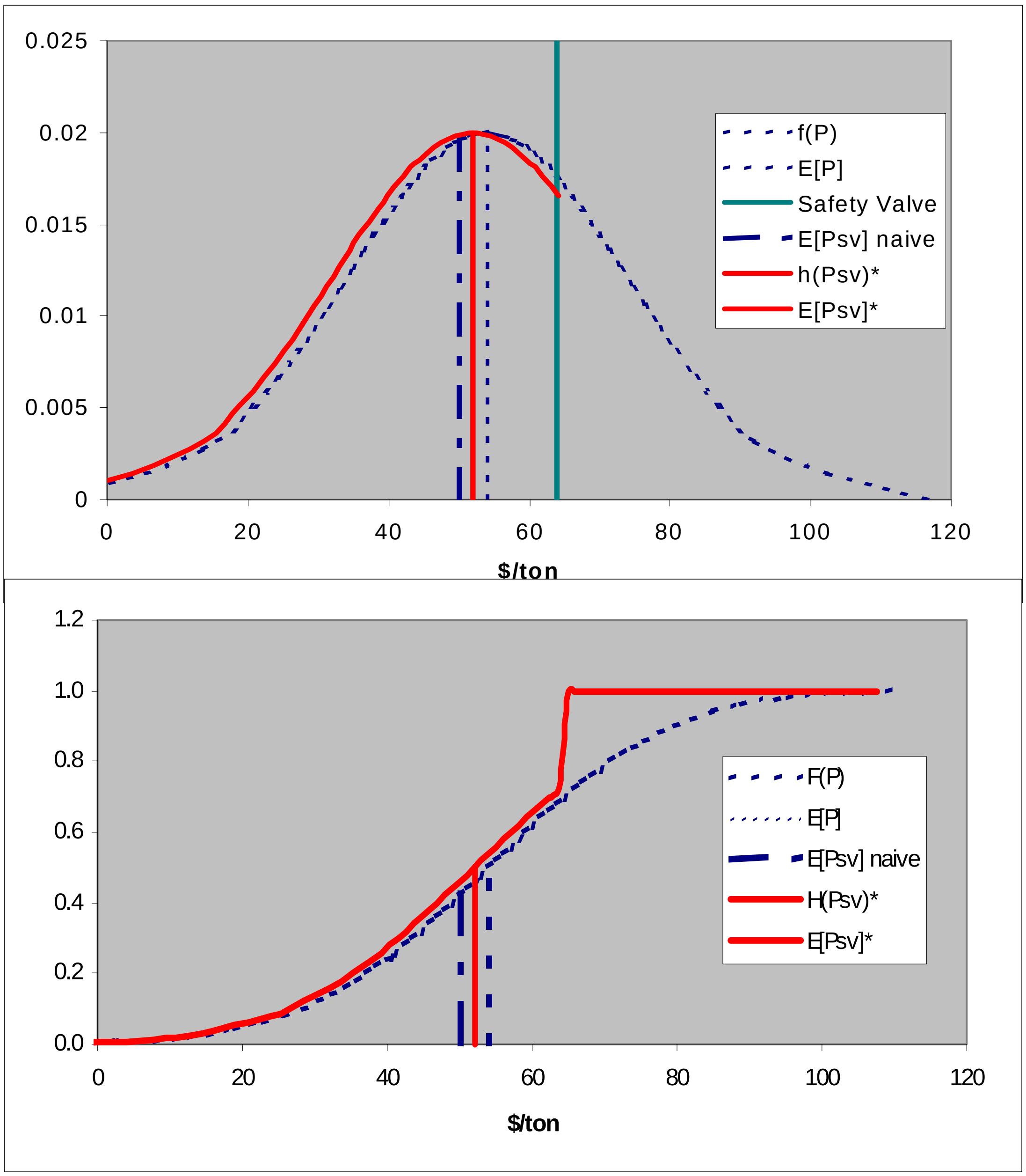

Figure D. Variation in electricity prices in the deterministic model with perfect foresight.

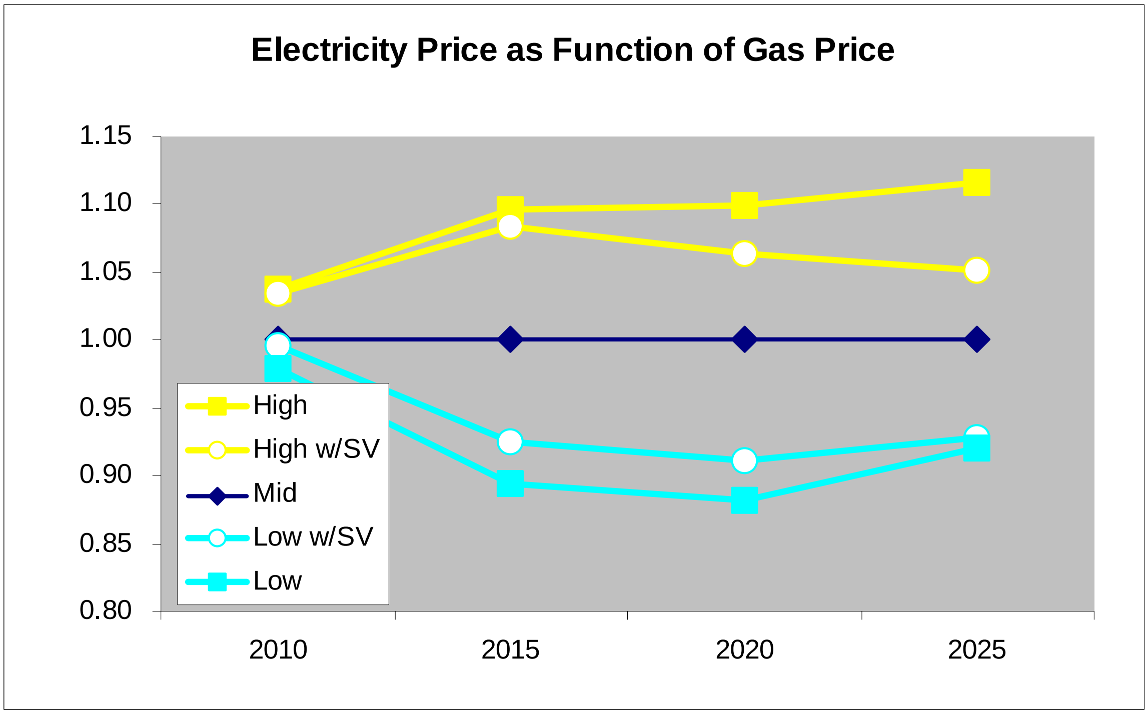

Figure E. Delta method approximations of outcomes under uncertainty.

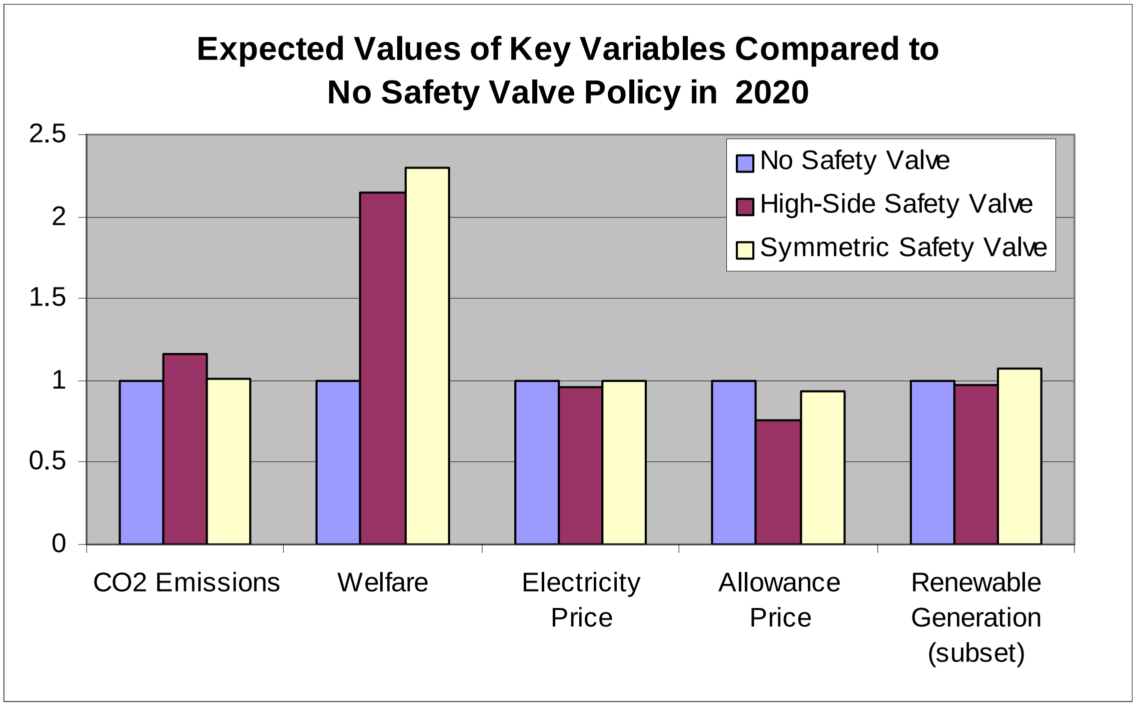

Figure F. Variation in electricity prices in the model with certain but imperfect foresight.

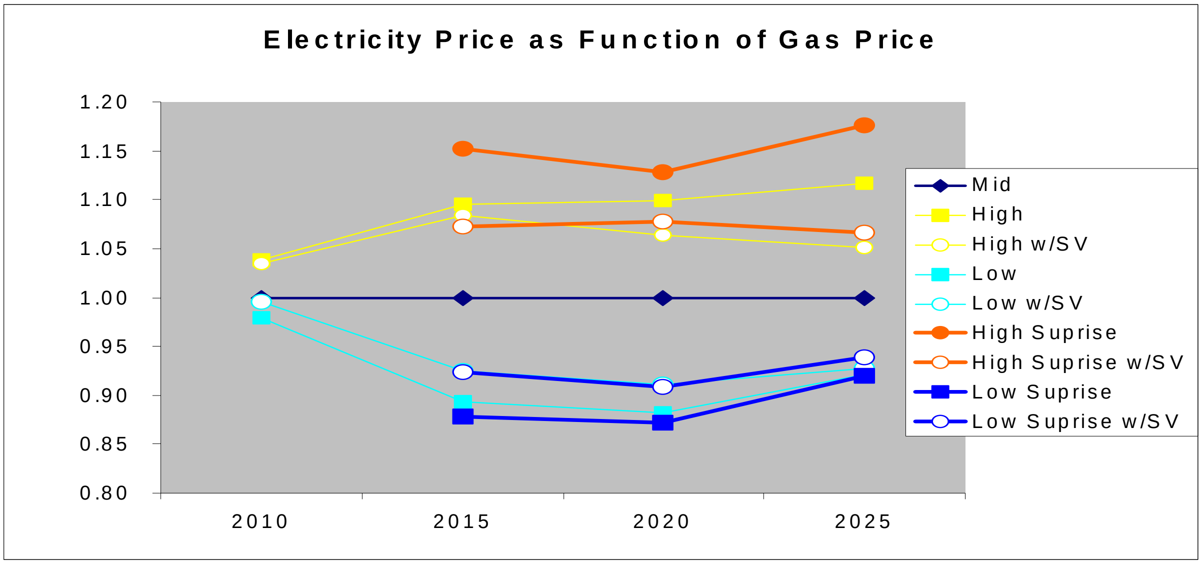

Figure G. Delta method approximations of outcomes in a model with certain but imperfect foresight.

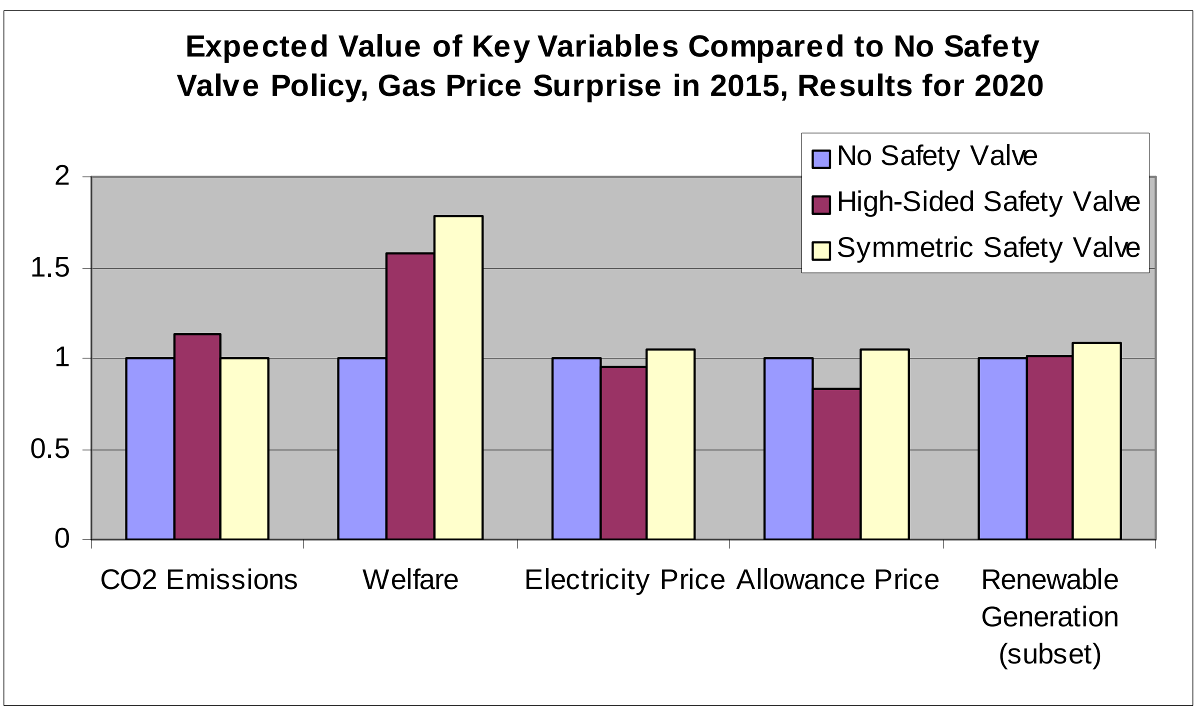

Table 1. Deterministic model with certain foresight, 2020.

	Low Gas Price	Low Gas Price w/ Symmetric Safety Valve	Mid Gas Price	High Gas Price w/ High-Side Safety Valve	High Gas Price
Gas Price ($/mmBtu)	4.42		6.31	8.21	
CO_2 Emissions (Mtons)	2,009	1,699	1,973	2,293	1,999
Welfare* (Billion $)	37.66	39.94	0	-6.85	-23.25
Electricity Price ($/MWh)	82.1	84.8	93.1	99.1	102.4
Allowance Price ($/ton)	33.0	43.5	51.1	59.7	74.1
Renewable Generation** (BkWh)	313	360	394	568	581

* Welfare compared to Mid Gas Price case.
** Underestimate because renewables include only changes in wind, landfill gas, geothermal. Biomass is held constant.

Table 2. Delta method approximation of key variables in model with uncertainty, 2020.

Expected Value $\mathrm{E}\left[\phi(\tilde{g})\right]$	**No Safety Valve**	**High-Side Safety Valve**	**Symmetric Safety Valve**
Gas Price ($/mmBtu)	6.31	6.31	6.31
CO_2 Emissions (Mtons)	1,983	2,313	2,015
Welfare* (Billion $)	13.82	29.62	31.80
Electricity Price ($/MWh)	91.43	88.19	90.78
Allowance Price ($/ton)	55.66	41.88	52.00
Renewable Generation** (BkWh)	494.5	482.3	528.2

* Welfare is the difference relative to the Mid Gas Price case.

**Underestimate because renewables include only changes in wind, landfill gas, geothermal. Biomass is held constant.

Table 3. Model with certain but imperfect foresight and a gas price surprise in 2015. Results for 2020.

	Low Gas Price	Low Gas Price w/ Symmetric Safety Valve	Mid Gas Price	High Gas Price w/ High-Side Safety Valve	High Gas Price
Gas Price ($/mmBtu)	4.42		6.31	8.21	
CO_2 Emissions (Mtons)	1,983	1,690	1,973	2,264	1,983
Welfare* (Billion $)	35.25	38.01	0	-13.85	-21.99
Electricity Price ($/MWh)	81.25	84.67	93.14	100.40	105.10
Allowance Price ($/ton)	32.14	43.28	51.14	59.42	68.42
Renewable Generation** (BkWh)	296	328	394	473	472

* Welfare is the difference relative to the Mid Gas Price case.

**Underestimate because renewables include only changes in wind, landfill gas, geothermal. Biomass is held constant.

Table 4. Delta method approximation of key variables in model with certain but imperfect foresight, results for 2020.

Expected Value $E[\varphi(\tilde{g})]$	**No Safety Valve**	**High-Side Safety Valve**	**Symmetric Safety Valve**
Gas Price ($/mmBtu)	6.31	6.31	6.31
CO_2 Emissions (Mtons)	1,992	2,256	1,982
Welfare* (Billion $)	12.67	19.97	22.59
Electricity Price ($/MWh)	93.18	88.84	92.04
Allowance Price ($/ton)	49.47	41.15	51.57
Renewable Generation** (BkWh)	374.6	377.1	407.4

* Welfare is the difference relative to the Mid Gas Price case.

**Underestimate because renewables include only changes in wind, landfill gas, geothermal. Biomass is held constant.

Output-Based Allocation of Emissions Permits for Mitigating Tax and Trade Interactions*

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ABSTRACT

The allocation of tradable emissions permits has important efficiency as well as distributional effects when tax and trade distortions are taken into account. We compare different rules for allocating carbon allowances within sectors (lump-sum grandfathering, output-based allocation (OBA), auctioning) and among sectors (historical emissions or value-added shares). The output subsidies implicit in OBA mitigate tax interactions, unlike grandfathering. OBA with sectoral distributions based on value added is similar to revenue recycling with auctioning. OBA based on historical emissions supports heavier polluters, more effectively counteracting carbon leakage, but at higher welfare costs. Less energy-intensive sectors are also sensitive to allocation rules.

I. INTRODUCTION

Increasingly in recent years, many countries have been incorporating economic instruments into environmental policy, particularly "cap-and-trade" policies that fix emissions limits and allow firms to trade the rights to emit up to that cap. The United States is expanding its use of marketable emissions permits from sulfur dioxide (SO_2) to nitrogen oxides (NO_x) and potentially mercury, and proposals to reduce CO_2 include emissions trading. The European Union (E.U.) is proceeding with an emissions trading system for controlling greenhouse gases. Other countries, including Canada, are considering an emissions trading program for greenhouse gases.

When emissions are capped, they become a scarce and valuable resource. An important political—and economic—question is how to allocate these pollution rents. Most economists, citing the large literature on the "double dividend," recommend that permits be auctioned so that the revenues can be used to lower other distortionary taxes in the economy that otherwise increase the cost of environmental regulation. In practice, however, governments prefer to forgo the revenues and allocate the permits gratis to the industries covered by the trading system. For example, in its acid rain program, the United States distributed all of the SO_2 allowances, less a small reserve, to existing coal-fired power plants, an annual value in the range of $2 billion. The European Union has mandated that member states freely distribute their permits, imposing a maximum of 5% for auctioning permits in the first trading period (2005–2007). The McCain-Lieberman Climate Stewardship Act of 2003, the main proposal on the table to limit greenhouse gas emissions in the United States, provides for sector-based allocations but also some share (to be specified) to go a special nonprofit corporation that would be established to benefit consumers, the Climate Change Credit Corporation (CCCC).

A common method for gratis allocation is "grandfathering," which gives participating firms a fixed number of allowances. That number is often determined by historical emissions or market shares, but the key aspect is that the allocation does not vary with changes in circumstances. In the absence of other market failures, this lump-sum allocation offers the same incentives and efficiency as auctioning permits. However, in giving away all the permits, the value of the rents transferred to incumbent firms can vastly outweigh their actual cost burden from the regulation.[i] Any increase in marginal production costs tends to be passed on to consumers, who get no relief from the allocation. Another distributional concern is that firms that enter later may not get any allocation and have to purchase all their permits on the market. Thus, attention is turning toward allocation methods that can be updated (or will update themselves) according to changing market conditions and composition.

Accordingly, one method of updating that is frequently advanced is output-based allocation (OBA). For example, a cap may still be placed on the emissions of several sectors and each sector would be granted a fixed number of those permits, but *within* each sector, individual firms would receive a share of the sector cap in proportion to their share of their industry's output. As market shares within an industry change, permit allocations are updated, such that each unit of output is accorded the same average permit allocation. However, since output is a control variable of the firm, the allocation policy itself has behavioral effects, which in turn tend to reduce the efficiency of the environmental policy. Specifically, the allocation creates a subsidy to output, which effectively distributes the emissions rents to consumers in the form of lower prices, relative to lump-sum allocations. However, from an efficiency perspective, that subsidy also limits incentives to reduce emissions through conservation and diverts attention toward lowering energy intensity.

Environmental policy, of course, does not operate in a vacuum. The efficiency of a standard Pigouvian tax or an equivalent emissions permit system relies on the assumption that markets are not otherwise distorted. Where distortions exist, environmental policy may exacerbate them, rendering simple Pigouvian policies suboptimal. We focus on two major examples that can justify support for output: (1) emissions leakage and (2) tax interaction.

Emissions leakage occurs when significant portions of an emitting industry escape regulation. This problem is of particular relevance for transboundary pollutants, since foreign sectors will be outside the jurisdiction of a domestic regulator. In greenhouse gas policy, this issue is known as carbon leakage. Since they bear no environmental burden, excluded producers suddenly have relatively low costs compared with participants. Industry production then tends to shift away from participants toward nonparticipants (who are still emitting costlessly). An output subsidy for participants would discourage such intraindustry shifting of production and emissions. Bernard et al. (forthcoming) show that when the products of the exempt firms cannot be taxed to reflect the value of the embodied emissions, an output subsidy may be warranted—to the extent these products are close substitutes for those produced by regulated firms.

Taxing labor income creates another kind of imperfection by distorting the labor-leisure trade-off; in a sense, it taxes all consumption goods at the same rate, making them more expensive and making consuming leisure more attractive relative to consuming goods.[ii] Adding an environmental policy that makes some consumption goods even more expensive further distorts this trade-off. Environmental policies that raise revenues that can be used to lower distorting labor taxes unambiguously raise welfare from the no-policy scenario. Policies that do not raise revenue (like grandfathered permits) must have positive environmental benefits that outweigh the increased deadweight loss from the labor tax on the margin.[iii]

By providing a subsidy to output, output-based rebating may mitigate some of the impact of the tax interaction effect compared with lump-sum distribution. The implicit subsidy lowers the price of the dirty good, making goods consumption in general less expensive and real wages higher. However, the gain from a reduced disincentive must be balanced against the higher abatement cost of achieving the same level of emissions reduction. The net result may (or may not) be an improvement over distributed permits in this situation.

Goulder et al. (1999) show that performance standards can generate fewer efficiency costs than distributed permits in this second-best system. In their model, performance standards are less costly the less abatement is to be done by output adjustment than by emissions rate adjustment.[iv] On the other hand, Jensen and Rasmussen (2000), using a general equilibrium model of the Danish economy, find that allocating emissions permits according to output dampens sectoral adjustment but imposes greater welfare costs than grandfathered permits. Dissou (forthcoming), in an application to greenhouse gas reductions in Canada, finds that performance standards can mitigate losses in gross domestic product, but welfare is lower relative to grandfathered permits.

Although performance standards bear similarities to output-based allocation, there are some important differences. Performance standards (particularly tradable ones) allocate permits according to output and the target emissions intensity. In theory, they could be set so as to equate marginal abatement costs across multiple sectors.[v] Such a result can be replicated with a multisector cap-and-trade system with OBA, but with a single set of allocations at the sector level. In practice, many different sectoral allocation rules are possible—and more plausible—than expected equilibrium average emissions. Since these sectoral allocations determine the relative subsidy for output, we will closely examine the effects of different rules for dividing an emissions cap among sectors.

We look at how well OBA can address these second-best efficiency issues relative to grandfathering or auctioning emissions permits. We begin with some theoretical background, using a partial-equilibrium analytical model, before proceeding to the general-equilibrium numerical analysis. We use a version of the computable general equilibrium (CGE) model GTAP-EG, modified to incorporate a labor-leisure choice, to look at how well OBA can address issues of equity and efficiency relative to grandfathering emissions permits or auctioning with revenue recycling and with trade effects.

We find that the rules for setting the initial sectoral caps play an important role in determining the changes in welfare, industrial production, employment, and trade induced by the emissions policy. OBA with sectoral distributions based on value added generates effective subsidies more like a broad-based tax reduction, performing nearly like auctions and clearly outperforming lump-sum allocations. OBA based on historical emissions supports the output of more polluting industries, which more effectively counteracts carbon leakage, but is more costly in welfare terms. With less contraction among polluting sectors, more reductions must be sought among less carbon-intensive sectors and final demand, signaled by a higher carbon permit price. However, due to the importance of the tax interaction problem, historical OBA remains less costly in net welfare terms than traditional permit grandfathering, at least for targets that are not too stringent. In all cases output-based rebating is less efficient than auctioned permits, which raise revenues that offset labor taxes, encourage more work, and achieve this in a manner that does not distort the relative prices of dirty and clean goods.

II. PARTIAL EQUILIBRIUM MODEL

To build intuition for the first-order effects of different allocation mechanisms, we first present a partial equilibrium model of the affected industry. In the next section, we incorporate these industry incentives into a general equilibrium setting, to better account for the incidence of allocation on all prices and interactions with the broader tax system.

Consider a perfectly competitive industry with a representative firm that is a price taker in both product and emissions markets. The unit cost function, $c(.)$, is represented as a decreasing, convex function of the emissions rate μ. In other words, the firm chooses a technological or input mix that implies a given emissions rate, and exhibits constant returns to scale, which corresponds to a constant per-unit cost. Let y be the output of our representative firm. Let p be the market price for the good produced, while the price of a pollution permit is measured by t. Consumer inverse demand $p(y)$ is downward sloping and in equilibrium equal to the market price. Let the emissions cap be $\bar{E}$.

Lump-Sum Allocation: Grandfathering or Auctioned Permits

With lump-sum allocation, such as grandfathering or auctioned permits, the allocation is invariant to firm behavior. When permits are grandfathered, we assume that this allocation is unconditional and is not affected by decisions to enter or exit the market. Consequently, the choices of emissions rate and output are unaffected by the allocation, at least in a partial equilibrium model.

Let A be the lump-sum allocation to the firm. (With 100% grandfathering, $A = \bar{E}$, while with 100% auctioning, $A = 0$.) Firm profits are

$$\pi^{LS} = (p - c(\mu) - t\mu)y + tA \tag{1}$$

By the first-order conditions, the firm equalizes the marginal cost of emissions rate reduction with the price of emissions,

$$-c'(\mu) = t \tag{2}$$

while the market price reflects the unit cost of production and the external cost of the embodied emissions:

$$p = c(\mu) + t\mu \tag{3}$$

This result corresponds to standard Pigouvian pricing. If each sector's emissions cap were initially set to generate socially optimal reductions, in a market with multiple sectors, trade across sectors would reproduce the same efficient emissions and product pricing—excluding other market failures and general equilibrium effects. With grandfathering, the firm (and its shareholders) receive windfall profits of tA, while auctioning permits raises revenues $t(\bar{E} - A)$.

Updating with Output-Based Allocation

With output-based allocation, the industry receives an allocation A, which is then distributed among the firms in proportion to their output over the relevant period. In equilibrium, the per-unit allocation is $a = A / y$, which a representative competitive firm takes as given. Although we present this representation as a result of an allocation rule with updating in the short run, in practice, the updating time frame may be long or lagged. The key point is that additional output today changes the discount value of the future allocation stream. By the same token, this implicit subsidy can also represent the long run effects of grandfathered permits that are conditional on continued operation.[vi]

The profit function for a representative firm within an industry is expressed as

$$\pi^{OBA} = (p - c(\mu) - t(\mu - a))y \tag{4}$$

The firm's profits are therefore reduced by the cost of the additional permits it must purchase (if $\mu > a$) or increased by the value of excess permits it can sell off (if $\mu < a$). To optimize profits, the firm equalizes the marginal cost of emissions rate reduction as in (2). However, given any emissions rate, the market price is lower than with lump-sum allocation by the value of the per-unit allocation:

$$p = c(\mu) + t(\mu - a) \tag{5}$$

The lower price means that in equilibrium with market demand, output will be higher. Consequently, with output-based allocation, the Pigouvian emissions price and corresponding emissions rate will lead to greater than optimal emissions. The dual to this problem is that to achieve the same level of emissions as the optimal case, the marginal price of emissions must rise and the emissions rate must fall. Thus, for a given amount of emissions reduction, output-based rebating raises the marginal cost of emissions reduction relative to efficient policy.

We next explore this result more formally. Consider two types of permit markets in which this industry might operate. In a restricted market, the industry has its own emissions target. In a broad-based market, the industry participates in a larger cap-and-trade system with other industries, each of which has its own allocation mechanism. An important point is that the subsidy is a function of not the industry average emissions rate but rather the average allocation. In a restricted market, the average emissions rate will equilibrate to equal the average allocation; in a broad-based market, it need not.

Restricted Permit Markets. In restricted permit markets, all the firms participating in a given permit market compete in a single allocation pool. These firms remain price takers both in product and in permit markets. Let us continue to consider representative firms, one for each sector, indexed by *i.* Total emissions for each restricted market are fixed at the level of emissions achieved with Pigouvian pricing, an equilibrium denoted by * (i.e., for sector *i*, $\overline{E}_i = \mu_i^* y_i^*$ where μ_i^* and y_i^* are the optimal emissions rate and output for sector *i*, satisfying Equations (2) and (3) with $t = MB$). Permits totaling $\overline{E}_i$ are then allocated among program participants in each sector according to output shares. The rebate to individual firms in sector *i* thus equals $a_i = \overline{E}_i / y_i$ per unit of output.

Let us denote this equilibrium with superscript *R*. In this case, the average permit allocation equals average emissions in each self-contained permit program, and $a^R{}_i = \mu_i^R$. Thus, $p(y_i^R) = c(\mu_i^R) < c(\mu_i^*) + t\mu_i^* = p(y_i^*)$. Given that $y_i^R > y_i^*$, because of the presence of the output subsidy, to achieve the required emissions level, average emissions rates will have to be lower: $\mu_i^R = \overline{E}_i / y_i^R > \overline{E}_i / y_i^* = \mu_i^*$. As a result, permit prices will be higher, reflecting the higher marginal cost of control: $t_i^R = -c'(\mu_i^R) > -c'(\mu_i^*) = MB$.

Figure 1 depicts the excess burden of output-allocated permits compared with the social optimum in this partial equilibrium setting. The dead-weight loss occurs in two parts: (1) higher-than-optimal production costs, and (2) the damages implied by emissions from the excess production, less the corresponding consumer surplus. In other words, even though total emissions are at their optimal level, the marginal damages from output still exceed the marginal benefits.

It is worth noting that applying separate cap-and-trade programs with output-based allocations to multiple sectors is equivalent to setting performance standards. When the sectoral allocation is based on the emissions corresponding to Pigouvian pricing, as in the case presented here, then marginal abatement costs will diverge according to the elasticity of demand for each sector's output. Alternatively, one could set the performance standards such that marginal abatement costs would be equalized; to replicate this method with OBA requires allocating more permits (compared with the Pigouvian levels) to sectors with relatively more elastic demand. Dissou (forthcoming) simulates this method, using a CGE model to assess the effects of performance standards, set for each sector to both equalize marginal abatement costs and achieve an overall emissions target. A similar method was used by Goulder et al. (1997). Effectively, this represents OBA with a different rule for allocating permits at the sectoral level.

Consequently, modeling performance standards to equalize marginal abatement costs does not represent OBA more generally, since the rule for determining the overall sector's allocation can vary, and it is important. Furthermore, with multiple sectors, it is a far more complicated policy problem to set performance standards so as to equalize marginal abatement costs, whereas markets achieve that with a multisector trading program with OBA.

Multisector Permit Markets. Of course, many pollutants—including greenhouse gases—are emitted from a variety of activities and rarely just a single sector. In this case, allowing permit trading across sectors in a broad-based market can allow for a more efficient allocation of effort. However, output-based allocation of permits can also affect the distribution of effort.

By the same logic as the restricted market model, equilibrium permit prices in the broad market must be higher than optimal, since the output subsidies limit conservation incentives, requiring more emissions rate reduction and higher marginal costs of emissions control. If the sectors are not identical—that is, if they display different cost structures, emissions, or demand elasticities—the implicit subsidies and their effects will vary.

In other words, suppose each sector's targets under restricted permit markets were set so that marginal abatement costs equal marginal benefits with lump-sum allocation, as just previously defined. With OBA, those costs now diverge, as the sector with relatively elastic demand compensate for less conservation by driving down its emissions rate (and driving up its marginal abatement costs) to a greater extent. With trade, marginal abatement costs are again equalized across sectors; the sectors with relatively inelastic demand will tend to increase their overcompliance and sell permits to those whose consumers would otherwise more easily conserve or find substitutes. Furthermore, as costs and thereby output change with multisector trade, the average allocation will not necessarily reflect average emissions in each sector.

To understand the intuition behind these results, consider this simple but extreme example: two sectors compete in a single permit market, each with output-based allocation of permits within the sector, but one sector has perfectly inelastic demand. Let Sector 1 be that sector; its total allocation equals $A_1 = \mu_1^* y_1^*$, and since the equilibrium output level does not change, its average allocation always equals $a_1 = \mu_1^*$. In an equilibrium with multisector emissions trading (denoted with superscript *M*), Sector 1 then has an output price of $p_1^M = c(\mu_1^M) + t^M(\mu_1^M - \mu_1^*)$. Meanwhile, Sector 2 faces more elastic demand. It receives a total allocation of $A_2 = \mu_2^* y_2^*$, which will correspond to an average allocation of $a_2^M = \mu_2^* y_2^* / y_2^M$. The price in that sector then equals $p_2^M = c(\mu_2^M) + t^M(\mu_2^M - \mu_2^* y_2^* / y_2^M)$. In a permit market equilibrium, we know that total emissions across sectors must equal the total cap: $\mu_1^M y_1^* + \mu_2^M y_2^M = A_1 + A_2$. Furthermore, the marginal costs of reducing emissions rates per unit of output must be equalized at the permit price: $-c'(\mu_1^M) = -c'(\mu_2^M)$.

Suppose the emissions price were equal to the optimal marginal abatement cost; whereas Sector 1 always supplies the optimal quantity, in Sector 2, with the output allocation subsidy, a greater quantity will be demanded. The emissions embodied in the extra output would violate the cap, so the permit price must rise and emissions rates fall in both industries to maintain the cap. Then, overall, Sector 1 will emit less than the socially optimal amount, and Sector 2 will emit more.

Alternatively, we can compare this equilibrium to that of restricted permit markets with OBA. With separate permit markets, consumers in the sector with inelastic demand reap the full benefit of the output subsidy, but efficiency is not affected. In Sector 2, efficiency losses are present, since the emissions rate and consumer price are lower than optimal. When these sectors are allowed to trade permits, the permit price would then equilibrate in between, with Sector 1 lowering emissions rates (being more than compensated by the subsidy transfer) and Sector 2 raising them (but still not as high as optimal emissions intensities), so that

$\mu_1^M < \mu_1^*$, $\mu_2^R < \mu_2^M < \mu_2^*$. For Sector 2, lower permit prices and lower control costs mean that consumer prices are even lower than in the restricted permit market case, even though the value of the allocation subsidy falls as well.[vii] Consumer prices in Sector 1 must also be lower; according to the first-order condition for profit maximization, if a firm wants to decrease its emissions rate and trade, its overall costs must be lower.

Taken from another view, output-based allocations can create false gains from trade, based on the extent to which abatement choices are distorted by the output subsidy. Sectors with relatively inelastic demand functions realize a comparative advantage in abatement arising, in a sense, from their greater ability to pass costs along to consumers.

The net effects of permit trading on welfare depend on whether the efficiency loss decreases as it is redistributed. Overcompliance in Sector 1 represents a real resource cost, but it allows Sector 2 to reduce its overcompliance. However, its output price then reflects even less of the cost of the embodied emissions. As the costs of reducing emissions rates are presumably convex, cost savings will arise from spreading overcompliance across the sectors. Thus, the question in the partial equilibrium problem is whether those savings outweigh the additional efficiency loss from more overproduction in Sector 2.

Summary and General Equilibrium Issues

The key tradeoffs between auctioning, grandfathering, and OBA can be divided into efficiency effects and distributional effects, which we summarize in Table. For each policy, the emissions cap determines the environmental benefits, while the allocation method determines the beneficiaries—and to some extent the costs. Auctioning permits benefits the government and taxpayers, since the revenues can expand public goods provision and/or offset other taxes. Grandfathering permits benefits incumbent firms and their shareholders; since marginal cost increases are passed along to consumers in any case, the lump-sum transfer represents windfall profits. However, new entrants are often excluded from these windfalls. Output-based allocation ensures new entrants equal opportunities for allocations, but the mechanism primarily benefits consumers, as the marginal subsidy to firms is passed along in the form of lower prices. Just as the rules for setting individual allocations under grandfathering determine the distribution of windfall profits, the rules for setting the sector-level cap under OBA determine which consumers benefit by setting the effective subsidy for each sector.

From an efficiency perspective, auctioning and grandfathering have the same impact on prices and costs—at least in the absence of other market failures. OBA, by weakening conservation incentives, raises the costs of achieving an emissions target, and in a multi-sector permit market, the overall efficiency loss depends on the distribution of the sector allotments and the effective subsidies.

In a general equilibrium framework, however, these output price effects are more important because of interactions with tax distortions and uncovered sectors. When labor markets are distorted by wage taxes, increases in product prices due to the emissions regulation lower the real wage further, imposing an excess burden. This burden is highest with grandfathering, while auctioning with revenues recycled toward lowering the labor tax minimizes the burden. Since OBA mitigates some of the product price increase, it also mitigates some of the excess burden from the labor market distortion. Similarly, when some sectors remain unregulated, price increases in the regulated sectors encourage consumers to substitute toward unregulated (and/or imported) products, increasing emissions from those sectors. OBA is the only allocation mechanism to mitigate this leakage problem directly, since it affects the relative prices of regulated and unregulated products; revenue recycling, on the other hand, affects only the relative wage rate.

To explore these trade-offs, we next apply this sectoral model of emissions regulation with output-based allocation to a general equilibrium model of the U.S. economy and the case of reducing CO_2.

III. GENERAL EQUILIBRIUM MODEL WITH TRADE AND TAXATION

Description

Since we are primarily concerned with the distributional and efficiency effects of emissions permit allocation mechanisms with taxes and trade, we employ a CGE model from the Global Trade Analysis Project (GTAP), which offers richness in calculating trade impacts. In particular, we can look in detail at the effects on a more diverse and disaggregated set of energy-using sectors than in most climate models.[viii] However, this static model is not designed specifically to study climate policy. It lacks the capability to examine certain issues of import, particularly dynamic responses, since it does not project energy use into the future or allow for technological change. It does, however, allow for capital reallocation. As such, our results should be considered illustrative of short- to medium-term effects (say, 3-5 years, a relatively short perspective for climate policy) on different sectors of implementing a carbon cap-and-trade program using different allocation mechanisms for emissions permits.[ix] Our impacts of interest include CO_2 emissions, production, trade, and employment by sector, as well as overall welfare, both in the United States and abroad, and carbon leakage.

The model and simulations in this paper are based on version 6.1 of the GTAPinGAMS package developed by Thomas Rutherford and documented for version 4 of the dataset and model in Rutherford and Paltsev (2000). The GTAP-EG model serves as the platform for the model outlined here. The GTAP-EG dataset is a GAMS dataset merging version 6 of the GTAP economic data with information on energy flows. A more complete discussion of the energy data used can be found in Complainville and van der Mensbrugghe (1998).

The model is a multi-sector, multi-region general equilibrium model of the world economy as of 2001. Energy requirements and carbon emissions are incorporated into this framework. The production function incorporates most intermediate inputs in fixed proportion, although energy inputs are built into a separate energy nest. Energy production is a CES function nested to three levels. At the lowest level, oil and gas relatively substitutable for one another (elasticity = 2) within the "liquid" nest, while "liquid" energy is less substitutable against coal in the "non-electric nest". Lastly, "non-electric" has low substitutability (0.1) against electricity in the "energy" nest. "Energy" itself has low substitutability (0.5) for the labor-capital composite from the "value-added" nest. Within the "value-added" nest, labor, private capital and public capital have unitary elasticity. Foreign and domestic varieties are substitutable for one another through a standard Armington structure, with the elasticity of substitution between the domestic variety and foreign composite set to half the elasticity of substitution among foreign varieties. The latter elasticities are largely derived from econometrically-based estimates as in Hertel et al. (2004).

Consumption is a composite of goods, services and leisure (further discussion of the labor-leisure choice is below). The energy goods oil, gas and coal enter into final demand in fixed proportions in the "energy" nest, and are unitary elastic with electricity. This composite is then substitutable at 0.5 with other final demand goods and services. Goods and services (including energy) are then substitutable against leisure; the derivation is given below.

Government demand is represented by a similar demand structure and private consumption, with the exception of the labor-leisure component. Government demand is held fixed through all of the experiments, although the funding mechanism (adjustment of a lump-sum tax or the tax on labor) varies as noted below.

Three features are added to the GTAP-EG structure allow us to model the impact of the policy scenarios. First, we add a carbon price. Second, the appropriate structure for simulating an output-based allocation scheme must be incorporated into the model. Third, the household is given a labor-leisure choice so that labor taxes are distorting. This distortionary tax allows us to conduct simulations recycling revenue from pollution permits to offset the distorting tax instrument.

Incorporating Output-Based Allocation. Several changes need to be made to the GTAP-EG code to incorporate output-based allocation of pollution permits. The profit function is not directly accessible in the MPSGE framework. Instead, we incorporate output-based permit allocation through the production function as a sector-based subsidy, combining it with side constraints on the values of a to duplicate the effect on the profit function above. Additionally, we create an additional composite fossil fuel nest to production. This allows us to incorporate the pollution permit as a Leontief technology, allowing us to track pollution permits through the model.

In the original GTAP-EG model, the treatment of energy goods does not allow for tracking of permits by sector. To track pollution permits, we need to ensure that one permit is demanded for each unit of carbon that enters into production. This is accomplished by separating the energy goods into a separate activity, a Leontief technology combining the polluting inputs with permits, into a new composite good (labeled *ffi* in the code, for fossil fuel input). The composite of permit and energy input is then included in the production block for the output good (*y*), ensuring that the implicit cost of the embodied emissions is reflected in the output price.

The next step is to incorporate the endogenous subsidy implied by the output-based allocation of permits within a sector. We mimic this in the form of an endogenous tax rate, *z*, into the sector's production function: $z_{i,r} = -t_r \dfrac{A_{i,r}}{y_{i,r}} / p_{i,r}$, where $A_{i,r}$ is the sector-level allocation for sector *i* of country *r*.

We consider two potential rules for determining this sector-level allocation. The historical emissions rule defines the sector's apportionment of pollution permits as the baseline unit demand for carbon multiplied by the percentage cap (κ_r) on emissions: $A_{i,r}^{Hist} = \kappa_r \sum_{fe} \chi_{fe,i,r} \phi_{fe,i,r}$. The variable $\chi_{fe,i,r}$ is the carbon coefficient for final energy good $fe \in \{coal, oil, gas\}$ in sector *i* of country *r*. The variable $\phi_{fe,i,r}$ represents the demand of the fossil fuel input. The value-added rule apportions the same number of permits based on each of the energy-using sector's share of value added in the base year: $A_{i,r}^{VA} = \sum_j A_{i,r}^{Hist} \frac{VA_{i,r}}{\sum_j VA_{j,r}}$.

The allocation mechanism is active only within those industries or sectors that demand carbon-containing fuel as an intermediate input. Within the GTAP-EG model, this excludes the following sectors: coal; petroleum and coal products; crude oil; natural gas; mining; and dwellings. Final demand for energy products is also subject to emissions permitting. The permits for these activities are freely traded in the same marketplace as those initially allocated based on output. We have a system where all pollution is subject to permitting and all permits are tradable within the country. The difference lies in how permits are distributed in the baseline and how revenues are recycled.

Incorporating Labor-Leisure Choice. The GTAP-EG model has also been extended by incorporating a labor-leisure choice into the household's decision. The procedure is documented in Fox (2002). Incorporating a labor-leisure choice allows us to treat the labor tax as a distorting tax, hence giving us a distorting policy instrument to offset with auction permit revenues. Since we have no data on labor taxes within the GTAP-EG database, we assume a labor tax rate of 40% within Annex B countries and a 20% tax rate within all other countries.[x]

In order to incorporate a labor-leisure choice in the model, it is necessary for us to construct a current level of leisure that is consistent with the output of the U.S. economy and the known characteristics of the U.S. supply of labor. The method presented here relies on the work of Ballard (1999). The consumer utility function is extended by adding a top CES nest allowing the household to substitute consumption of leisure for consumption of goods and services. The top nest of Figure 1 illustrates this structure, with Leisure and the consumption composite combined in a CES function with an elasticity of sig_lsr.

From this top CES nest of the consumer utility function, we derive demand for leisure, and the corresponding expressions for the uncompensated and compensated leisure demand and labor supply elasticities (ε_L and $\varepsilon_L|_{\bar{u}}$).[xi] Ballard (1999) suggests that reasonable values for the supply elasticities are $\varepsilon_L = 0.1$ and $\varepsilon_L|_{\bar{u}} = 0.3$.

Ballard emphasizes that the choice of the time endowment parameter, or how many hours are in a day, determines the total-income elasticity of labor supply. This can have a material impact on the relative responsiveness of changes in tax policy. For example, if the total time endowment is too large relative to the benchmark level of hours worked, the responsiveness of labor supply to a policy change can be implausibly large, despite the fact that the other parameters describing the labor market are well within the range of generally accepted values. To establish the initial value for leisure, we define an additional variable representing the number of hours worked, such that the sum of earned income at the initial wage rate and other (non-wage) income is equal to the benchmark value of final demand. This particular parameterization suggests that leisure is worth about one-quarter of the final demand for goods and services.

Lastly, we establish the benchmark value of the elasticity of substitution between labor and leisure, given econometric estimates of ε_L and $\varepsilon_L|_{\bar{u}}$ and the benchmark level of expenditure on goods and services, as well as the total amount of leisure consumed at the benchmark. The elasticity of substitution varies by country. In the United States, it is 1.736, and it varies between 1.358 and 2.528 elsewhere.

Policy Experiments

The McCain-Lieberman Climate Stewardship Act of 2003 (CSA) proposes to cap emissions in 2010–2016 to 2000 levels, eliminating a decade of increase.[xii] In this spirit, we set the basic policy goal to be a similar 14% reduction of CO_2 emissions from the base-year level (2001 in our case). The CSA also provides for sector-level apportionment to covered emissions sources,[xiii] with broad consideration given to historical emissions, as well as shares to the Climate Change Credit Corporation (CCCC). Details—including the actual shares and the distribution methods within sectors to the firms—are left to future rulemakings by the Commerce Department secretary and the administrator of the Environmental Protection Agency. It is also unclear whether CCCC would use the revenues from permit sales to offer lump-sum rebates (dividends) to consumers, lower federal taxes, or otherwise target the funds. In other words, this overall framework, should it be enacted, seems to offer a wide range of possibilities for allocation; hence, it is important to understand the consequences of alternative mechanisms.

To concentrate on the effects of U.S. program design, we refrain for now from modeling policy changes in other countries, including the European Union. Incorporating the carbon policies under development in other regions would have other general equilibrium effects; however, they are unlikely to change the relative impacts of the U.S. policy scenarios, which we assume are undertaken unilaterally.[xiv]

We conduct four experiments to assess the relative impact of using an output-based allocation scheme compared with other permit allocation methods:

Grandfather: Permits are distributed unconditionally among firms in all sectors (except final demand). This is the equivalent of a lump-sum rebate of all permit revenues.

Auction: All permits are sold—no gratis distribution.

Historical OBA: Allocations to firms are updated based on output shares within their sector. At the sector level, caps are based on historical emissions. Allocations are made in sectors with intermediate energy demand.

Value-Added OBA: Allocations to firms are updated based on output shares within their sector. Sector shares are based on historical shares of value added. Allocations are made in sectors with intermediate energy demand.

In essence, for the gratis distribution scenarios, permit allocation occurs in two phases. First, the rule for allocating the sector's share of the emissions cap is chosen. We consider historical emissions shares and value-added shares as examples. (The sector allocations for these scenarios will be reported in Table 4.) The second phase of permit allocation requires choosing a rule for distributing the sector-level cap among the firms. Our scenarios encompass two options: within each sector, permits are either grandfathered in lump-sum fashion among firms or updated based on output.

In all cases, permits are traded across sectors. Those permits not distributed gratis (i.e., those for final demand in the non-auction scenarios) are auctioned and flow back into the government budget. Furthermore, government revenue is held constant through a labor tax, so any excess revenues from permit sales are recycled to lower the labor tax rate.[xv] By capping the entire economy and allocating to all sectors, we simulate a somewhat more comprehensive carbon trading program than the CSA, which excludes consumers and agriculture.

Results

Perhaps the most striking result is the effect the allocation mechanism has on the permit price, the indicator of marginal abatement cost. Permit prices for the different scenarios are given in

Table 3.

As indicated in the theory, grandfathering and auctioning permits, as lump-sum allocation mechanisms, have nearly identical impacts on the permit price, which we find is about $43/ton C for the 14% reduction. The slight variation occurs due to the general-equilibrium effects of revenue recycling. While the theory predicts that OBA should raise permit prices, this does not hold with any significance for the value-added OBA scenario in general equilibrium, since the implicit subsidies are spread across the economy much like a broad-based tax reduction. However, historical OBA generates a nearly 50% permit price premium compared to the other scenarios. In this case, the implicit subsidy from updating favors large emitters and discourages conservation, thereby requiring the economy to seek reductions elsewhere.

To explore the reasons behind and consequences of these price changes, we divide the other numerical results into two categories: distributional impacts and indicators of efficiency and effectiveness.

Distributional Impacts.

Permit Allocation. Table 4 reports the sector allocations for the gratis allocation options of historical emissions vs. historical value added. In both cases, permits are allocated to sectors with primary energy demand (which tends to exclude primary energy producers from large allocations).xvi Permits representing final demand (residential energy use, representing a little less than 7%) are assumed to be held by the government and auctioned.

Unsurprisingly, the distribution of emissions is quite different from that of the overall economy. The electricity sector accounts for just over two-fifths of national emissions, followed by transport with another quarter, and the chemical industry with nearly a tenth. On the other hand, services represent two-thirds of value added; all other sectors have modest shares—less than 10%.

The distributional effects are interpreted differently if allocations are grandfathered than if they are updated based on output. The GTAP model does not have positive operating profits in equilibrium, assuming instead that average and marginal costs are equalized. As a consequence, the distribution rule does not have allocative effects under grandfathering. Rather, permit allocation shares indicate the distribution of windfall profits by sector to their shareholders (in this case, the representative agent). On the other hand, with OBA, the distribution rule does have allocative effects, but no profit impacts. Although the model does not allow for producer surplus calculations, other variables can serve as indicators of the distributional effects, including sector output and employment. The relative price results will also reflect consumer impacts by sector.

Carbon Emissions. The distribution of effort, in one sense, is represented in Table 5 by the percentage change in emissions across sectors. Nearly all the scenarios had the same impact on the distribution of carbon emissions reductions—with the dramatic exception of historical OBA. In this scenario, emissions reductions shift away from heavy historical polluters—like refining, mining, transport, and other manufacturing—toward other sectors, including agriculture, construction, and particularly final demand.

Surprisingly, we see that several non-energy-intensive sectors have smaller emissions reductions in the Historical OBA scenario. The table also reveals that the sector-specific effects can be much larger than the aggregated effects across broad categories.

Output. Although emissions impacts seem similar across auction, grandfathering, and value-added OBA, the impacts on output do not. For example, non energy intensive sectors benefit from revenue recycling in an auction and from implicit subsidies in VA OBA; however, they contract along with the energy intensive sectors in a grandfathering system. In the case of historical OBA, we see that, corresponding to the emissions impacts, production in historically polluting sectors is significantly higher: the size of the contraction in output is roughly half that in other scenarios. Most notably, electricity production, which falls by 6% in the other scenarios, registers a negligible change with historical OBA, and the transport sector goes from a roughly 8% contraction to a 2% drop.

With this shift from output substitution as a means for emissions reductions in the major polluting sectors, the carbon price rises dramatically to induce reductions elsewhere. This price rise has the added effect of raising the value of the permit allocations, reinforcing the subsidies. For the non energy intensive sectors, the implicit subsidy is outweighed by the higher permit and production costs, lowering output. Several of these sectors also experience greater trade exposure, and in some cases output falls more than with grandfathering.

Employment. The changes in emissions and output have two kinds of impacts on employment by sector. On the one hand, the decrease in emissions leads to a substitution away from energy inputs and toward labor and capital, tending to increase labor demand. On the other hand, a decrease in output tends to decrease labor demand. Furthermore, we will see that the allocation regime affects the after-tax real wage, which also has employment impacts across the economy.

Thus, in employment, we see some sectors increasing their labor demand, while others decrease it, as indicated by the grey cells in Table 7. With auctioned or value-added OBA permits, in general, energy-intensive sectors decrease their demand while non-energy-intensive sectors increase labor demand slightly. With grandfathering, more sectors decrease their labor demand, due to the tax interaction costs which lower the real wage; this is the only scenario in which overall employment falls. With historical OBA, some energy-intensive sectors actually expand employment, while non-energy-intensive sectors decrease theirs, due to the changes in output. In all scenarios, employment in primary energy industries falls significantly, and the allocation regime has relatively little impact.

Efficiency and Effectiveness.

Price Impacts. For the sectors that use energy and electricity as inputs, their own price effects tend to be mirror opposites of the output effects. One puzzle is that under historical OBA, several of the less energy intensive sectors have both lower output and smaller emissions reductions, despite higher permit prices, relative to the other scenarios. The answer lies in the effects of allocation on the different energy prices.

Table 8 reports the changes in prices of energy products. Primary energy prices received by producers are exclusive of the permits required by the downstream users; however, they are affected by the costs of producing the energy good. For example, the petroleum products and (to a lesser extent) natural gas sectors burn fossil fuels in order to make the product, and to this extent, permit requirements are reflected in the producer price. Downstream consumers (or intermediate good producers) face energy costs that include permit costs as well as the producer price.[xvii] Crude oil is only used by the petroleum industry, and consumers of electricity do not have to buy additional permits; those costs become embedded in the electricity price, as do any subsidies from an OBA.

For all primary energy producers, the prices received are lowest and consumer prices highest with historical OBA, due to the higher permit price. The allocation associated with historical OBA also has important impacts on refined fossil fuels and electricity, which are major emitting sectors.

In all but the historical OBA scenario, the price of electricity rises significantly—a signal for other sectors to conserve. With historical OBA, the price actually falls, meaning that electricity is cheaper than without the carbon policy. Correspondingly, more price pressure is placed on other primary energy sources, since more reductions must then come from those sources.

Similarly, with refined petroleum products, in all but historical OBA, producer prices rise, due to the higher production costs associated with abatement and permit requirements.

Those prices then fall with historical OBA, due to the substantial value of the allocation. Indeed, while the producer prices for coal and natural gas fall due to decreased demand, oil consumption is higher in this scenario than in the others. The consumer prices inclusive of permit costs rise less for oil products than for other energy sources (in the other scenarios, the oil price rise is roughly 90% of the natural gas price rise; with historical OBA, it is 70% of the natural gas price rise). This relative price change makes oil more attractive—despite its higher emissions content—resulting in a shift toward oil (or less of a reduction in oil consumption). This shift explains the lesser pressure on the price of crude oil.

More importantly, this relative price change dominates the effect of higher permit prices in the incentives for the non energy intensive sectors, as their shift from gas to oil increases their emissions intensity under historical OBA relative to the other scenarios (see Table 5). As a result, with almost all of the producing sectors reducing their emissions abatement, either due to the subsidy or the relative price change, final demand ends up shouldering a disproportionate share of the burden in the historical OBA scenario.

Trade. Since historical OBA causes the greatest distortion in relative prices, it has the greatest impact on trade. Table 9 presents the change in net exports, evaluated at the base year prices, in millions of dollars. The net export position of the heavy emitters falls much less dramatically, and it even rises for electricity and for energy intensive sectors overall. The chemicals industry benefits particularly from lower petroleum prices. However, some sectors that are relatively more competitive in other allocation regimes see their net exports fall with historical OBA, namely other industries and services. These sectors face higher permit prices and labor costs and little subsidies.

Net exports of primary energy products increase in all scenarios, since domestic demand declines; the exception is that increased electricity production with historical OBA increases coal imports. Overall, net exports fall most with historical OBA and least with grandfathering, in part since domestic consumption is lowest in the latter scenario.

For the most part, these changes amount to less than 1% of production, with the exception of some energy industries and mining. The decline in net exports of natural gas and mining represented 2-3% of production in those sectors in all but the historical OBA scenario. The increase in crude oil net exports represents 17% of production in the historical OBA scenario and 23% of production in the others, due to the drop in domestic consumption. Overall, however, little difference emerges among the scenarios, as total net exports fall by 0.03% of the total value of production; on the other hand, the carbon leakage profiles do vary.

Carbon Leakage. Carbon leakage is driven primarily by the relative price effects for energy intensive sectors. Since historical OBA is the only scenario to target those sectors specifically, it proves the most effective at limiting the increase in emissions among trading partners, with 12.5% of domestic reductions offset be increases abroad, compared to 15.4% with the other scenarios. Value-added OBA, grandfathering, and auctioned permits have nearly identical impacts on leakage. Thus, while OBA has the potential to reduce carbon leakage relative to other methods, the rule for allocating at the sector level is important for determining this effect.

Table 10 compares leakage by sector, focusing on the two scenarios of auctioning and historical OBA, since the others have such similar results to allocation by auction. A major impact of historical OBA is felt in the reduction of the leakage rate for refined products, chemicals, and transportation. However, this effect is partly offset by fewer reductions at home. Leakage pressure is increased for other industries and services, some of which have very high rates, but they compose a smaller share of total emissions reductions.

On the other hand, primary energy sectors exhibit strongly negative leakage. Since the U.S. reduces consumption of primary energy, imports fall and so do foreign emissions. Emissions related to producing primary energy products are on a smaller order of magnitude than those from burning those products, but the foreign reductions are as (or more) significant as the domestic ones in that sector. As such, the data seem to indicate that foreign primary energy production (particularly of coal) is more emissions intensive than production at home. The shift in U.S. demand also seems to increase emissions from foreign final demand, due to downward pressure on global energy prices.

Table 11 shows carbon leakage by trading partner for each of the allocation scenarios. An important caveat is that we do not model an emissions cap in other countries, like the EU, which would tend to limit leakage to those trading partners. For example, if the rest of the Annex I parties were to adhere to their Kyoto emissions caps, then more than half of the leakage concern of a U.S. cap would be eliminated.

Summary Economic Indicators for the United States. The relative efficiency of the allocation policies is reflected in the change in the summary economic indicators, reported in Table 12. The primary indicator is welfare, which is measured in equivalent variation. Change in total production is another indicator of economic impacts.[xviii] Impacts on workers, consumers, and tax payers are reflected by changes in employment, the real wage, and the labor tax rate.

Trade impacts are indicated by the overall change in net exports and in emissions leakage. The emissions permit price reflects the marginal cost of abatement.

Overall, the 14% reduction induces less than a 1% change in the summary economic indicators for all the scenarios. These impacts are consistent with the range found by other climate models.[xix] Although the changes may seem small, the relative effects of the allocation scenarios are still illustrative.

As predicted, auctioning permits with revenue recycling produces the smallest welfare loss for the United States, measured in equivalent variation. In fact, the welfare impact is slightly positive, implying a small double-dividend effect, as this mechanism leads to an increase in the real wage and employment, due to the significant fall in the labor tax rate. In other words, the implicit energy tax is less distorting on the margin than the existing labor tax.

Grandfathering permits entails the largest welfare cost—and the largest drop in the real wage—since the loss of tax revenues from the economic contraction requires an increase in the labor tax rate.[xx]

The most notable effects of historical OBA are the dramatic rise in the price of permits, which are a 50% more costly than all of the other scenarios, and the fall in the leakage rate, which is three-quarters that of the others. The revenue adjustments were minor—even slightly negative, because of the greater value of the permits withheld for auction.[xxi] The impacts on overall welfare are closer to those with grandfathering than with auctions; however, historical OBA had the smallest decrease in production, and little impact on the real wage. In other words, the mitigation of the consumer price increases, easing the burden of tax and trade distortions, roughly offset the inefficiencies in allocating emissions reductions.

Value-added OBA functions a good deal like a consumption tax reduction and therefore approaches auctioning in efficiency (though not perfectly so, since not quite all sectors generating value added receive allocations). Overall, the welfare cost was only slightly larger than auctioning. This scenario saw a slight increase in the real wage, due not only to a small drop in the tax rate but also to a more even distribution of the effective output subsidies throughout the economy.

It is also interesting to note the effects of U.S. emissions permit allocation on global welfare, although the magnitudes are admittedly small in percentage terms (less than 0.3% of GDP for any given region). The overall international impacts of U.S. climate policy are presented in Table 13.

We see that the small welfare increase in the U.S. with auctioned permits is outweighed by losses abroad, implying the double dividend does not hold overall. And although historical OBA eases some of the burden of tax and trade distortions compared with grandfathering for the United States, this set of output subsidies seems to have the strongest impact on the welfare of trading partners; it ranks the lowest in terms of global welfare.

Sensitivity Analysis. The relative efficiency of OBA is obviously sensitive to the rule for distributing the permits at the sector level. However, it is also sensitive to the degree of the tax distortion to the labor supply. Obviously, at the extreme, if labor supply were perfectly inelastic, labor and consumption taxes would have no distorting effect, grandfathering permits would be equivalent to auctioning, and any OBA would be less efficient. Therefore, there should be some labor supply elasticity at which the benefit from using output subsidies to mitigate tax interactions is outweighed by the cost in terms of distorting relative prices. To better assess the role of the labor-leisure tradeoff in determining the relative efficiency of the allocation scenarios, we conduct sensitivity analysis with respect to the elasticity of labor supply.

Figure 3 illustrates the welfare changes arising from different combinations of the compensated and uncompensated labor supply elasticities. Both the absolute and relative elasticities are important, since the value placed on leisure rises as the difference between the two elasticities increases (Ballard 1999). The combination (2,3) is closest to our baseline values of (0.2, 0.29) for compensated and uncompensated elasticities, respectively. We see that more inelastic labor supply compresses the differences between the policies, while higher elasticities make them more pronounced. Within this range, however, the rankings remain the same.

Another question regards the relationship between the ranking of the policy options and the stringency of the target.

Figure 4 reveals that relative costs are not proportional to the emissions reduction target. In these simulations, using OBA with the historical emissions rule has some benefits relative to grandfathering for targets up to an 18% reduction; for more stringent emissions caps, however, the distortions created by the corresponding subsidies outweigh the benefits, and historical OBA becomes increasingly the most costly option.

Finally, we also conducted analysis for *net* emissions targets, such that each policy would achieve the same amount of emissions reductions globally, net of leakage. The results are very much the same; despite historical OBA's superiority in mitigating leakage, that policy is still dominated by auctioning and value-added OBA for all reduction targets. The net target does extend the range over which historical OBA is preferred to grandfathering, with those welfare costs crossing at a target of around a 21% reduction.

IV. CONCLUSION

The use of emissions trading represents an important step in improving the efficiency of environmental regulation. However, the tremendous implicit value of the capped emissions—particularly in the case of carbon—raises important political and economic questions about how to allocate the permits. The practical reality seems that the vast majority of permits will be given away gratis to the regulated industries. If so, can we design the allocation process to mitigate the problems of welfare costs, tax distortions, and carbon leakage?

The answer may be that these goals pose trade-offs. In terms of the overall economic indicators—welfare, production, employment, and real wages—auctioning with revenue recycling is the preferred allocation method. Value-added OBA, which effectively attempts to embed the proportional tax rebate into consumer prices, is a fairly close second by these metrics, improving notably over lump-sum grandfathering.

However, in terms of mitigating carbon leakage, historical OBA is clearly the most effective. For the same reason—that it limits price rises in energy-intensive sectors—it also poses the greatest costs on other sectors. While this result would imply important efficiency losses relative to grandfathering in a partial equilibrium model, we find that these losses are offset by gains in terms of mitigating tax interactions in a general equilibrium framework. However, for more stringent targets, historical OBA can indeed become more costly in welfare terms.

This raises the issue of whether the sector allocation rule can be optimized to target some set of these goals. For example, what might the optimal subsidies to limit leakage look like, and what impact might they have on overall welfare?[xxii] What are the relative roles of carbon intensity, trade exposure, and demand elasticities in determining these subsidies?

Although theory offers some support that OBA can enhance the economic efficiency and environmental additionality of emissions trading in a second-best setting, the question remains whether OBA can pass legal muster under world trade rules.[xxiii] From an economic point of view, taxing the carbon content of imports from countries with lesser climate policies can similarly combat leakage; however, such an import tax is very likely to be challenged in the World Trade Organization. Since allocation is perceived as a component of environmental regulation, not a direct subsidy, OBA may enjoy legal leeway. On the other hand, since OBA can create a significant subsidy to industry, it has the potential for abuse in practice. Indeed, unlike with sector-specific performance standards or emissions trading systems, with broad-based, intersectoral trade, OBA can be designed to offer subsidies that outweigh the direct effect of the regulatory compliance costs. Resolving the question of whether OBA is a legal policy tool (and under what conditions) could have important implications for the efficiency—and inefficiency—of future climate policies.[xxiv]

Overall, however, we find relatively small magnitudes for the welfare costs of the policies. To put in some perspective, since climate change may increase the risk of extreme weather events, the annual welfare costs of the policies we simulate range to the U.S. from about 0-3% of the infrastructure and property losses from Hurricane Katrina.[xxv] Although the estimated differences among the policies may seem small in relative terms, that does not mean policy makers need not be judicious in designing an emissions cap and trade program for carbon. For one, we have modeled a broad-based policy with complete coverage of the economy; to the extent that an actual policy will cover only a restricted number of sectors, domestic leakage can be as much a concern as carbon leakage abroad, and the same overall reduction target will be costlier to meet. Furthermore, over time, targets will need to be more stringent, and incentives for technological change will be more important, meaning policy choices that become embedded in national carbon emissions regulation will have greater consequences.

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Appendix

MPSGE Code for Output-Based Allocation

Fossil fuel production activity (crude, gas and coal):

```
$prod:y(xe,r)$vom(xe,r)  s:(esub_es(xe,r))  id:0

o:py(xe,r) q:vom(xe,r) a:gov(r) t:ty(xe,r)

      i:pa(j,r)$(not fe(j)) q:vafm(j,xe,r) p:pai0(j,xe,r) a:gov(r)

+t:ti(j,xe,r) id:

      i:pl(r) q:(ld0(xe,r)/pl0(r)) p:pl0(r) a:gov(r) n:ltax(r) id:

 i:pr(xe,r) q:rd0(xe,r)

i:pffi(fe,xe,r)$vafm(fe,xe,r)q:(vafm(fe,xe,r)*pai0(fe,xe,r)) id:
```

Non-fossil fuel production (includes electricity and refining):

```
$prod:y(i,r)$nr(i,r)   s:0  vae(s):0.5  va(vae):1

+                       e(vae):0.1  nel(e):0.5 lqd(nel):2

+                       oil(lqd):0 col(nel):0 gas(lqd):0

o:py(i,r) q:vom(i,r)  a:gov(r) t:ty(i,r) a:ra(r)

+n:z(i,r)$(cap(i) and subject(r) and sum(fe,vafm(fe,i,r)))

i:pl(r) q:(ld0(i,r)/pl0(r)) p:pl0(r) a:gov(r) n:ltax(r) va:

i:rkr(r)$rsk q:kd0(i,r) va:

i:rkg$gk q:kd0(i,r) va:
```

```
i:pa(j,r)$(not fe(j)) q:vafm(j,i,r) p:pai0(j,i,r) e:$ele(j)
+a:gov(r) t:ti(j,i,r)
i:pffi(fe,i,r)$vafm(fe,i,r) q:(vafm(fe,i,r)*pai0(fe,i,r)) fe.tl:
```

Fossil fuel composite (fuel-plus-permit):

```
$prod:ffi(fe,i,r)$(vafm(fe,i,r)) s:0
o:pffi(fe,i,r) q:(vafm(fe,i,r)*pai0(fe,i,r))
i:pcarb(r)#(fe)$(cap(i) and subject(r)) q:carbcoef(fe,i,r) p:1e-6
i:pa(fe,r) q:vafm(fe,i,r) p:pai0(fe,i,r) a:gov(r) t:ti(fe,i,r)
```

OBA-related side constraints:

```
$constraint:z(i,r)$(cap(i) and subject(r) and sum(fe,vafm(fe,i,r)))
z(i,r)*py(i,r)*y(i,r)*vom(i,r) =e= (-ebar(i,r)*y(i,r))*pcarb(r);

$constraint:ebar(i,r)$(cap(i) and subject(r) and sum(fe,vafm(fe,i,r)))
ebar(i,r) * y(i,r) =e= PctCap(r) * (OBA_Hst * alloc_hst(i,r) +
OBA_Va * alloc_VA(i,r)) ;
```

Table 1: Summary of Allocation Mechanism Effects

Allocation Mechanism	*Distributional Effects*	*Efficiency Effects*
Auctioning (with revenue recycling)	Benefits taxpayers; Permit costs are passed on to consumers	Revenue recycling mitigates fall in real wage, though high prices in regulated sectors can encourage emissions leakage
Grandfathering (lump-sum allocation)	Gives windfall rents to incumbent firms and their shareholders; no allocation for expanded production or new entrants; Permit costs are passed on to consumers	High prices interact with labor tax distortions and encourage emissions leakage
Output-based allocation (updating)	Benefits consumers with smaller price increases; Allocations guaranteed for expanded production or new entrants	Smaller product price increases mean less interaction with labor taxes and less emissions leakage; However, conservation is discouraged and marginal abatement costs are higher; Relative prices among regulated sectors are also distorted

Table 2: Allocation Policy Scenarios

	Auction	*Grandfather*	*Historical OBA*	*VA OBA*
Sector-level allocation	None	May be based on historical emissions, value added, or other	Based on historical emissions	Based on historical value added
Within-sector allocation to firms	None	Lump-sum	Updated based on output shares	Updated based on output shares

Table 3: Emissions Price (2001 dollars per ton C)

Auction	*Grandfather*	*Hist. OBA*	*VA OBA*
$ 49.21	$ 48.59	$ 70.47	$ 49.87

Table 4: Sector Shares of Carbon Cap with Historical and Value-Added Rules

Sector	*Historical*	*Value-Added*
Electricity	*47.6%*	*1.5%*
Petroleum and coal products (refined)	9.7%	0.1%
Chemical industry	7.6%	3.0%
Other mining and metals	1.6%	1.2%
Paper-pulp-print	1.0%	1.9%
Iron and steel industry	0.8%	0.6%
Emissions intensive	*20.7%*	*6.7%*
Agriculture	1.0%	1.2%
Food products	1.0%	2.8%
Transport equipment	0.3%	2.0%
Other machinery	0.3%	4.2%
Other manufacturing	0.3%	3.1%
Textiles-wearing apparel-leather	0.2%	1.0%
Wood and wood-products	0.2%	1.0%
Other industry	*3.3%*	*15.2%*
Natural gas	1.2%	0.1%
Crude oil	0.4%	0.0%
Coal	0.0%	0.1%
Primary energy	*1.6%*	*0.2%*
Other services	2.5%	50.0%
Trade, wholesale and retail	1.4%	16.3%
Construction	0.2%	6.7%
Services (excl. transport)	*4.1%*	*73.0%*
Transport	*22.9%*	*3.4%*
Total permits allocated	**1,306,099**	**1,306,099**

Table 5: Percentage Change in Emissions

Sector	*Auction*	*Grandfather*	*Hist. OBA*	*VA OBA*
Electricity	*-19.9*	*-19.9*	*-19.2*	*-19.9*
Petroleum and coal products (refined)	-13.5	-13.5	-11.9	-13.6
Chemical industry	-9.7	-9.7	-8.7	-9.6
Other mining and metals	-29.2	-29.2	-24.8	-28.9
Paper-pulp-print	-9.0	-9.0	-8.1	-8.9
Iron and steel industry	-7.8	-7.8	-7.0	-7.7
Energy intensive	*-11.6*	*-11.6*	*-10.4*	*-11.6*
Agriculture	-10.5	-10.6	-12.3	-10.4
Food products	-9.3	-9.4	-8.9	-9.2
Transport equipment	-6.9	-6.9	-5.2	-6.7
Other machinery	-6.5	-6.5	-4.8	-6.3
Other manufacturing	-6.3	-6.3	-4.5	-6.1
Textiles-wearing apparel-leather	-7.8	-7.9	-6.4	-7.7
Wood and wood-products	-6.6	-6.5	-4.6	-6.4
Other industry	*-7.6*	*-7.7*	*-7.4*	*-7.6*
Natural gas	-7.2	-7.3	-9.0	-7.4
Crude oil	-8.8	-8.9	-8.0	-9.0
Coal	-24.7	-24.6	-25.2	-24.8
Primary Energy	*-7.7*	*-7.8*	*-8.8*	*-7.9*
Other services	-12.2	-12.4	-7.6	-11.9
Trade, wholesale and retail	-6.2	-6.3	-3.9	-6.0
Construction	-10.1	-10.0	-11.1	-10.0
Services (excl. transport)	*-0.1*	*-0.1*	*0.0*	*-0.1*
Transport	*-32.3*	*-32.3*	*-30.4*	*-32.1*
Final Demand	*-8.9*	*-9.0*	*-13.1*	*-9.1*
Total	**-14.0**	**-14.0**	**-14.0**	**-14.0**

Table 6: Percentage Change in Output

Sector	*Baseline value (billions of $)*	*Auction*	*Grandfather*	*Hist. OBA*	*VA OBA*
Electricity	*258,050*	*-5.8*	*-5.9*	*-0.4*	*-5.8*
Petroleum & coal products (refined)	145,767	-10.9	-10.9	-8.2	-10.9
Chemical industry	716,372	-1.9	-2.0	-0.7	-1.9
Other mining	272,266	-4.0	-4.3	-2.0	-4.1
Paper-pulp-print	391,641	-0.3	-0.4	-0.3	-0.3
Iron and steel industry	142,544	-0.8	-0.9	-0.8	-0.8
Energy intensive	*1,668,589*	*-2.12*	*-2.24*	*-1.26*	*-2.14*
Agriculture	221,217	-0.2	-0.4	-0.4	-0.2
Food products	744,582	0.0	-0.2	-0.1	0.0
Transport equipment	661,162	-0.1	-0.2	-0.3	-0.1
Other machinery	787,603	0.0	-0.1	-0.7	0.0
Other manufacturing	705,388	-0.1	-0.3	-0.7	-0.1
Textiles-wearing apparel-leather	270,617	-0.3	-0.6	-0.4	-0.4
Wood and wood-products	227,138	-0.2	-0.3	-0.3	-0.2
Other industry	*3,617,707*	*-0.09*	*-0.26*	*-0.44*	*-0.11*
Natural gas	49,657	-5.3	-5.3	-6.6	-5.4
Crude oil	39,395	-5.0	-5.0	-4.5	-5.1
Coal	32,630	-16.1	-16.0	-16.5	-16.2
Primary Energy	*121,682*	*-8.08*	*-8.09*	*-8.55*	*-8.19*
Other services	7,051,427	0.3	-0.1	-0.2	0.2
Trade, wholesale and retail	2,456,004	0.1	-0.1	-0.1	0.0
Construction	1,351,225	-0.1	-0.2	-0.1	-0.1
Dwellings	758,281	0.5	0.3	-0.1	0.0
Services (excl. transport)	*11,616,937*	*0.10*	*-0.07*	*-0.11*	*0.05*
Transport	*670,410*	*-7.8*	*-8.2*	*-2.0*	*-8.0*
Total[xxvi]	**17,953,375**	**-0.38**	**-0.54**	**-0.36**	**-0.42**

Table 7: Percentage Change in U.S. Labor Demand

Sector	*Baseline Labor Demand (billions $)*	*Auction*	*Grandfather*	*Hist. OBA*	*VA OBA*
Electricity	*29.5*	*0.1*	*-0.3*	*7.8*	*0.0*
Petroleum & coal products (refined)	2.1	-2.3	-2.6	2.1	-2.5
Chemical industry	128.3	-0.7	-1.0	0.3	-0.8
Other mining	58.7	-0.4	-0.6	-0.1	-0.5
Paper-pulp-print	91.4	0.2	-0.1	0.0	0.1
Iron and steel industry	34.8	0.2	0.0	-0.3	0.1
Energy intensive	*315.2*	*-0.3*	*-0.6*	*0.1*	*-0.4*
Agriculture	34.1	0.2	-0.1	0.1	0.1
Food products	103.9	0.3	0.0	0.2	0.2
Machinery	355.3	0.1	-0.1	-0.4	0.1
Other manufacturing	177.3	0.1	-0.2	-0.6	0.0
Textiles-wearing apparel-leather	58.3	0.0	-0.4	-0.3	-0.1
Wood and wood-products	47.6	0.2	-0.1	-0.1	0.1
Other industry	*776.4*	*0.2*	*-0.1*	*-0.3*	*0.1*
Natural gas	9.2	-7.2	-7.3	-9.0	-7.4
Crude oil	3.3	-8.8	-8.9	-8.0	-9.0
Coal	6.8	-24.7	-24.6	-25.2	-24.8
Primary energy	*19.3*	*-13.7*	*-13.7*	*-14.5*	*-13.8*
Services	2,689.8	0.3	0.0	0.0	0.2
Trade, wholesale and retail	945.2	0.3	0.0	0.0	0.2
Construction	418.9	-0.1	-0.2	0.0	-0.1
Dwellings	5.7	0.7	0.3	0.1	0.1
Services (excl. transport)	*4,059.6*	*0.2*	*0.0*	*0.0*	*0.1*
Transport	*184.6*	*-0.4*	*-0.6*	*1.8*	*-0.5*
Total	**5,384.60**	**0.12**	**-0.15**	**0.00**	**0.03**

Table 8: Emissions Price and Percentage Change in Energy Prices

Sector	*Auction*		*Grandfather*		*Hist. OBA*		*VA OBA*	
Permit Cost	*Excl.*	*Incl.*	*Excl.*	*Incl.*	*Excl.*	*Incl.*	*Excl.*	*Incl.*
Petroleum & coal products (refined)	2.5	18.8	2.5	18.6	-2.2	22.3	2.6	19.1
Natural gas	-3.2	21.6	-3.1	21.4	-3.8	32.4	-3.1	22.1
Coal	-14.9	77.8	-14.8	76.7	-15.6	118.0	-14.8	79.1
Crude oil	-4.0		-3.9		-3.3		-4.0	
Electricity	9.4		9.3		-1.5		9.5	

Table 9: Change in Net Exports
(millions of 2001 dollars)

Sector	*Auction*	*Grandfather*	*Hist. OBA*	*VA OBA*
Electricity	*-629*	*-615*	*47*	*-639*
Petroleum and coal products (refined)	-551	-506	1,739	-593
Chemical industry	3,470	3,467	4,323	3,360
Other mining and metals	-7,958	-7,705	-2,539	-7,917
Paper-pulp-print	-461	-432	-439	-447
Iron and steel industry	-1,464	-1,448	-286	-1,475
Energy intensive	*-6,963*	*-6,624*	*2,799*	*-7,071*
Agriculture	-357	-280	-630	-307
Food products	-309	-216	-676	-262
Transport equipment	-450	-545	-1,773	-492
Other machinery	1,120	861	-3,358	1,141
Other manufacturing	-210	-406	-3,367	-227
Textiles-wearing apparel-leather	-494	-365	-912	-475
Wood and wood-products	-139	-130	-404	-125
Other industry	*-839*	*-1,082*	*-11,119*	*-746*
Natural gas	-861	-850	-282	-861
Crude oil	9,103	9,109	6,546	9,086
Coal	20	19	-24	21
Primary Energy	*8,261*	*8,278*	*6,240*	*8,246*
Other services	1,823	1,755	-1,602	1,862
Trade, wholesale and retail	171	179	-201	174
Construction	-6,435	-6,302	-1,348	-6,498
Services (excl. transport)	*-4,441*	*-4,368*	*-3,152*	*-4,463*
Transport	*-129*	*-127*	*-60*	*-130*
Total	**-4,741**	**-4,538**	**-5,245**	**-4,803**

Table 10: Carbon Leakage in the Largest Emitting Sectors

Sector	*Auction (Grandfather, VA OBA similar)*			*Historical OBA*		
	Reductions, 1000 MT C	*leakage, % of sector reductions*	*leakage, % of total leakage*	*Reductions, 1000 MT C*	*leakage, % of sector reductions*	*leakage,% of total leakage*
Electricity	*121,366*	*10*	*35.2*	119,634	*10*	*41.6*
Petroleum & coal products (refined)	18,691	44	22.5	14,936	25	13.8
Chemical industry	9,237	37	10.5	8,490	31	9.5
Other mining and metals	2,509	49	3.8	2,614	46	4.4
Paper-pulp-print	1,126	14	0.5	1,050	18	0.7
Iron and steel industry	755	79	1.9	696	105	2.7
Energy Intensive	*32,317*	*42*	*39.2*	27,786	*31*	*31.0*
Agriculture	1,263	30	1.2	1,555	29	1.6
Food products	1,115	13	0.5	1,103	18	0.7
Transport equipment	288	12	0.1	228	22	0.2
Other machinery	234	30	0.2	180	82	0.5
Other manufacturing	207	65	0.4	153	150	0.8
Textiles-wearing apparel-leather	232	39	0.3	198	63	0.5
Wood and wood-products	171	10	0.1	126	21	0.1
Other industry	*3,510*	*25*	*2.8*	3,542	*34*	*4.4*
Natural gas	1,280	-118	-3.9	1,580	-100	-5.7
Crude oil	497	-285	-3.7	409	-286	-4.3
Coal	23	-965	-0.7	24	-1129	-1.0
Primary energy	*1,800*	*-178*	*-8.3*	*2,013*	*-150*	*-11.0*
Other services	1,965	21	1.3	1,399	42	2.1
Trade, wholesale and retail	1,043	15	0.5	672	31	0.8
Construction	279	38	0.3	319	38	0.4
Services (excl. transport)	*3,287*	*20*	*2.1*	*2,390*	*38*	*3.3*
Transport	*35,289*	*16*	*15.4*	*30,206*	*12*	*12.8*
Final Demand	*21,760*	*20*	*13.7*	*33,758*	*14*	*17.8*
Total	**219,330**	**15.4**	**100.0**	**219,330**	**12.5**	**100.0**

Table 11: Carbon Leakage as Percentage of U.S. Reduction

Country	*Auction, Grandfather, VA OBA*	*Hist. OBA*
Europe	4.3	3.4
Canada	1.2	0.7
Japan	1.0	0.9
Other OECD	0.4	0.3
Former Soviet Union	1.0	0.9
Central European Associates	0.6	0.5
Annex I	*8.4*	*6.7*
China (incl. HK & Taiwan)	1.9	1.7
India	0.6	0.6
Brazil	0.4	0.3
Other Asia	1.4	1.2
Mexico + OPEC	1.0	0.7
Rest of World	1.6	1.3
Total	**15.4**	**12.5**

Central European Associates include Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia.

Table 12: Summary Indicators for the United States

Indicator	*Unit*	*Auction*	*Grandfather*	*Hist. OBA*	*VA OBA*
Welfare	% change in equivalent variation	0.00	-0.05	-0.04	-0.01
Production	% change	-0.38	-0.54	-0.36	-0.42
Employment	% change	0.12	-0.15	0.00	0.03
Real wage	% change	0.46	-0.59	-0.02	0.09
Labor tax change	percentage pts	-1.81	0.00	-0.34	-0.40
Carbon leakage	% of reductions	15.4	15.3	12.5	15.3
Permit price	$/metric ton C	$49.21	$48.59	$70.47	$49.87

Table 13: Change in Global Welfare
(Equivalent Variation; Millions of USD)

Country	*Auction*	*Grandfather*	*Hist. OBA*	*VA OBA*
United States	443	-4,582	-3,814	-1,202
Rest of World	-579	-380	-1,595	-661
World	-136	-4,962	-5,409	-1,863

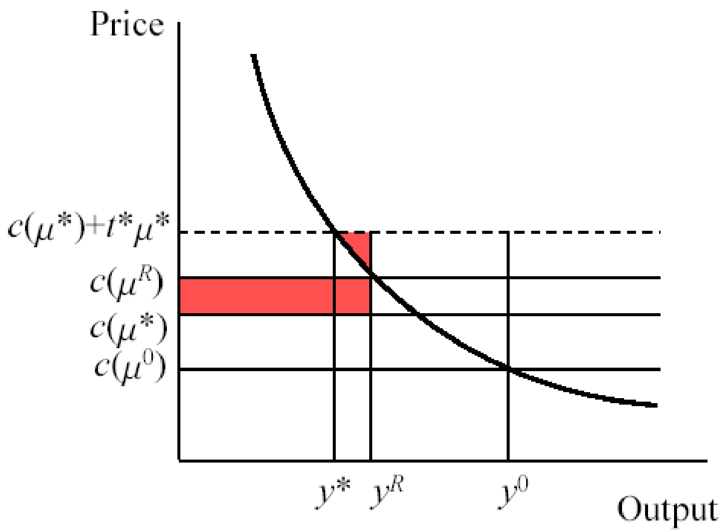
Figure Captions

Figure 1: Partial Equilibrium Efficiency Loss from OBA

Figure 2: Household utility function

Figure 3: Sensitivity to Labor Supply Elasticities

Figure 4: Sensitivity to Target Stringency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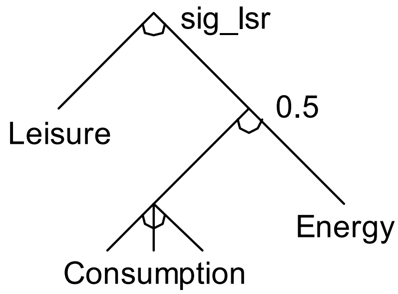
$c(\mu^R)$
$c(\mu^*)$
$c(\mu^0)$
y^*
y^R
y^0
Output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Leisure
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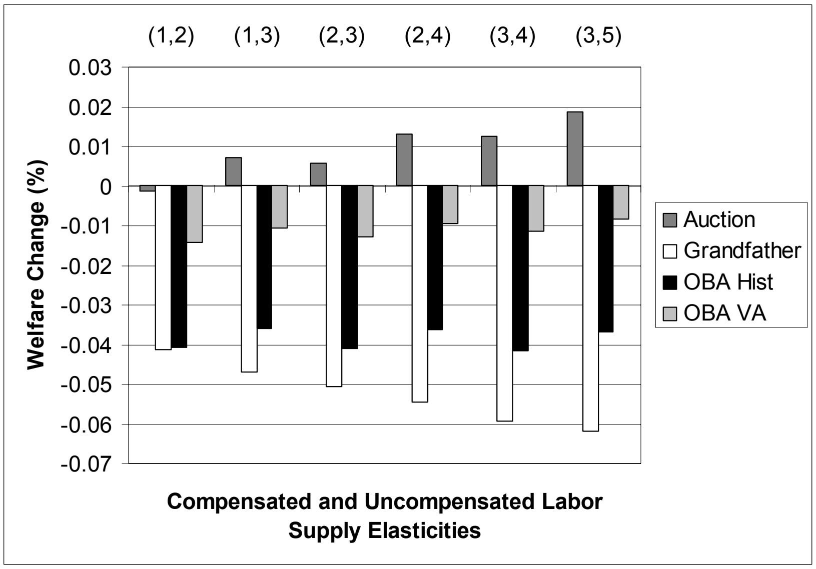
Energy
Consumption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(1,3)
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-0.02
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-0.04
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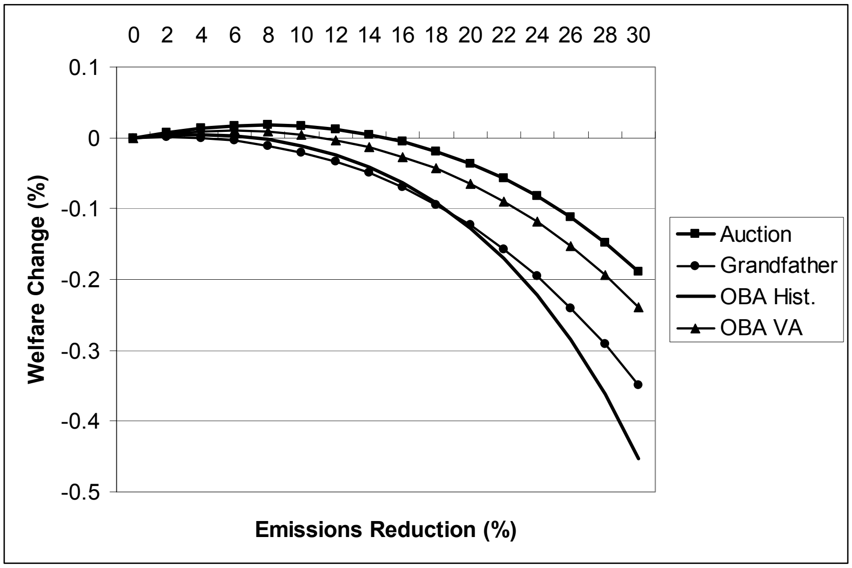
-0.06
-0.07
Welfare Change (%)
Auction
Grandfather
OBA Hist
OBA VA
Compensated and Uncompensated Labor Supply Elasticities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0
-0.1
-0.2
-0.3
-0.4
-0.5
Welfare Change (%)
Emissions Reduction (%)
Auction
Grandfather
OBA Hist.
OBA VA

ENDNOTES

[i] See Burtraw et al. (2002) and Bovenberg and Goulder (2001).

[ii] For a comprehensive collection of the tax interaction literature, see Goulder (2002).

[iii] See e.g. Parry (1996) and Goulder et al. (1997). Fullerton and Metcalf (2001) make the distinction that policies that create scarcity rents (as opposed to policies that raise no revenue) are those that interact with labor tax distortions.

[iv] Parry and Williams (1999) also consider performance standards.

[v] This is the method of Dissou (forthcoming) and Goulder et al. (1999).

[vi] In other words, if the firm loses the permits if it exits the industry, the allocation becomes an operation subsidy that lowers long-run average costs by *tA/y* per unit. See also Boehringer et al. (2002).

[vii] See Fischer (2003).

[viii] We report impacts on 18 nonenergy sectors as well as 5 energy sectors. Most of the major climate models are much more highly aggregated, with 5 or fewer nonenergy sectors (Fischer and Morgenstern 2003). Some have more detail in modeling specific energy supplies. However, there are climate models based on GTAP, such as recent versions of ABARE-GTEM, that can offer richness in all of these dimensions.

[ix] The implicit assumption is that capital reallocates itself more quickly than production functions change. For example, given a real depreciation rate of 5% and an economy-wide real growth rate of 3%, then stopping investment in a sector allows it to shrink by 8% a year relative to the economy. The modest changes in production we see can then be accomplished within a couple years.

[x] Tax data are an area targeted for improvement in GTAP (Babiker et al. 2001).

[xi] See Fox (2002) for the full derivation.

[xii] After that period, emissions are to be further reduced to 1990 levels, though not below, as specified in the Kyoto Protocol targets.

[xiii] These are electric generation, industrial production, commercial activities, and transportation.

[xiv] For instance, including the EU emissions trading program would effectively change the baseline against which we evaluate the U.S. policies. The main relative change would regard emissions leakage to the EU, since emissions are theoretically capped for certain sectors there.

[xv] We did conduct some experiments in which the government budget was held constant through a lump-sum tax. This is the equivalent of taking back a portion of the lump-sum-rebated permit revenue. For the gratis scenarios, the difference was very small, since permit revenues are small and possibly offset by labor supply reactions. Of course, an Auction with lump-sum tax becomes equivalent to grandfathering.

[xvi] This assumption runs somewhat counter to the CSA, which allocates many of the transport sector permits to the upstream energy suppliers.

[xvii] Crude oil does not embody permit costs; those requirements are revealed in the refined oil prices.

[xviii] Production is measured using Laspeyre's volume index, in which changes are valued at *ex ante* prices, so they do not reflect price changes but actual output changes.

[xix]For example, Paltsev et al. (2003) find a welfare cost of 0.05% in 2010 for the McCain-Lieberman CSA Phase I target, with no banking, albeit with the MIT-EPPA model, which is also based on GTAP. EIA (2003) find a decline in GDP of 0.6% in the longer run, by 2025. Over that same timeframe, Smith (2004) finds a GDP loss of 0.7% with grandfathering and 0.4% with enough auctioning to offset revenue changes; however, they project larger

welfare losses than they other studies. Smith et al. (2003) explain that these larger impacts are driven by key intertemporal optimization assumptions in their model (which are absent in this one); when they remove perfect foresight and the ability of consumers to adjust consumption over time, they find consumption losses of less than 0.06%.

[xx] For this reason, grandfathering permits with a lump-sum tax adjustment fares slightly better than this scenario with the labor tax adjustment.

[xxi] For this reason, there would be little difference between lump-sum and labor tax revenue adjustments.

[xxii] This question is a general equilibrium variation of that posed by Bovenberg and Goulder (2001), who calculated the gratis permit shares needed to hold industry profits harmless.

[xxiii] For further discussion, see Fischer et al. (2003).

[xxiv] The European Union has its own "state aid" rules, and the European Commission, in monitoring the national allocation plans, seems to be frowning on explicit updating schemes; however, most plans have aspects of gratis allocation that are not truly lump sum, being conditional on production, and expectations for the second commitment period allocations that create expectations similar to OBA incentives. In the United States, OBA is explicitly allowed—even encouraged—in the formulation of state allocation plans for NO_x trading in the Northeast.

[xxv] Preliminary estimates by Marshall and Hicks (2005) place these costs at $157 billion.

[xxvi] Total is the total value of output, which includes intermediate goods, unlike final demand or GDP.

Ann Wolverton's Comments on the Fisher and Fox paper and the Burtraw, Kahn, and Palmer paper

Prepared for the Proceeding for the Market Mechanism and Incentives Workshop, October 17-18, 2006

- Both papers examine issues relevant to the design of cap-and-trade programs.

    - Fischer and Fox paper focuses on how the permits are allocated and trade-offs between efficiency and equity including different ways to update based on output or value-added

    - Burtraw et al. paper looks at how a safety valve could be used to increase the efficiency of cap-and-trade programs through dynamic adjustment to cost information revealed by permit prices.

- Fisher and Fox - Allocation Mechanisms

    - Auction – can offset other distortions with revenue
    - Grandfathering – cannot offset other distortions with revenue; firms see windfall profits due to value of the allocated permits. This profit is not passed on to consumers in the form of lower electricity prices.
    - Output-based – reallocation based on decision variable. This reallocation introduces inefficiencies into the market by expanding output but distributes rents to consumers as a decrease in prices.
    - Value-added based – less inefficiency because broad based distribution of rents, lower price for consumers

- Comments on Fisher and Fox:

    - Potentially larger rents – risk of political jockeying; rent seeking reallocation of permits that can lead to policy distortions particularly when stakes are large → does this differ across different methods?
    - Perhaps related to this is the question of what happens when assumption of perfect competition is relaxed (at least for industries with a few big industry leaders)
    - A more explicit comparison with performance standards would be useful. How do output-based allocations compare to performance standards?
    - How sensitive are the results to assumptions, e.g, labor-leisure elasticity of substitution; other elasticities; labor tax.
    - What if the U.S. joined in multi-lateral cooperation? Does it change the relative ranking? Does it change the distance between them when rated in terms of efficiency?
    - Also related to the Burtraw et al paper, how does a hybrid cap-and-trade rank? Are the effects similar? Do different incentives for technology change lead to a decrease in marginal costs?

- In terms of regulatory stringency, some estimates predict that greenhouse gas emission will need to decrease by one-half over time to stabilize atmospheric concentrations. At higher reductions, do changes in welfare continue to widen (across the options)? What are the driving factors?

- Comments on Burtraw, Kahn and Palmer:

  - What is the trade-off between policy certainty (for firms) and getting it right through adjustment over time?
  - How important is it for firms to know the role of government? And the rules of the game? (versus modifying the rules over time – firms may then hedge against banked allowances losing value over time). The adjusted rule would have to be estimated beforehand to minimize uncertainty → could get the rule wrong.
  - Interaction between safety valve and banking seems important to evaluate. More generally, behavioral effects/responses from other firms may change the analysis (such as effects on innovation that may decrease marginal costs).
  - How do other alternative mechanisms for dealing with uncertainty compare? (e.g., incentives for development of alternative fuels → RFS, subsidies, etc.?)
  - Does it create perverse incentives for government? Some of the problems with RECLAIM could have been averted with more flexibility in design (such as banking). With safety valves, there may not be an incentive to pay as close attention to design since you have a ready out.
  - Looking at the case where the marginal benefit curve is not flat seems like an interesting extension (cases other than CO_2)

- What are the interaction/synergies between the mechanisms discussed in the two papers? It is possible that updating, which increases the inefficiency some amount, could be used as an option to re-evaluate whether the number of permits was correctly allocated based on cost information revealed by the market → adjustment mechanism incorporated?

Arik Levinson's Discussant Comments on Fischer and Fox and Burtraw, Kahn, and Palmer

Fischer and Fox "Optimal Output-Based Allocation of Emissions Permits for Mitigating Tax and Trade Interactions"

Intro

- Fischer/Fox, good economist/contrarians, put forth good argument for case where trading is not necessarily, second best (or even third best).

- Long economic history picking on bad govt. policies various govts have enacted (makes for entertaining analysis). Fischer/Fox have moved on -- now picking on bad policies govts might be thinking of someday adopting: periodically updating the allocation of emissions permits based on firms' output. Not the first to model this type of thing.
  - Also F/F make nice point. Grandfathering itself has an element of OBA in it, in that it is a subsidy for continued operation of firms that might otherwise go out of business, if they'd lose their allocation by doing so.
  - Oates & Schwab 1988, Heutel and Fullerton 2006.

- This paper succeeds at convincing me of several things I would not have guessed before I started reading the paper:
  - Can it be optimal to adjust permit allocations among firms based on their output? (In second best world, yes.)
  - If tradable permits are handed out among various sectors, should we allow cross-sector trade?

- Great paper. Presents partial eq'm model, which has much of the intuition. We know it's wrong, but we can see all the moving parts and know which parts of the intution are likely to generalize and which way the PE biases might work. Then presents CGE. We know that's wrong too, but have no idea why.

Issues

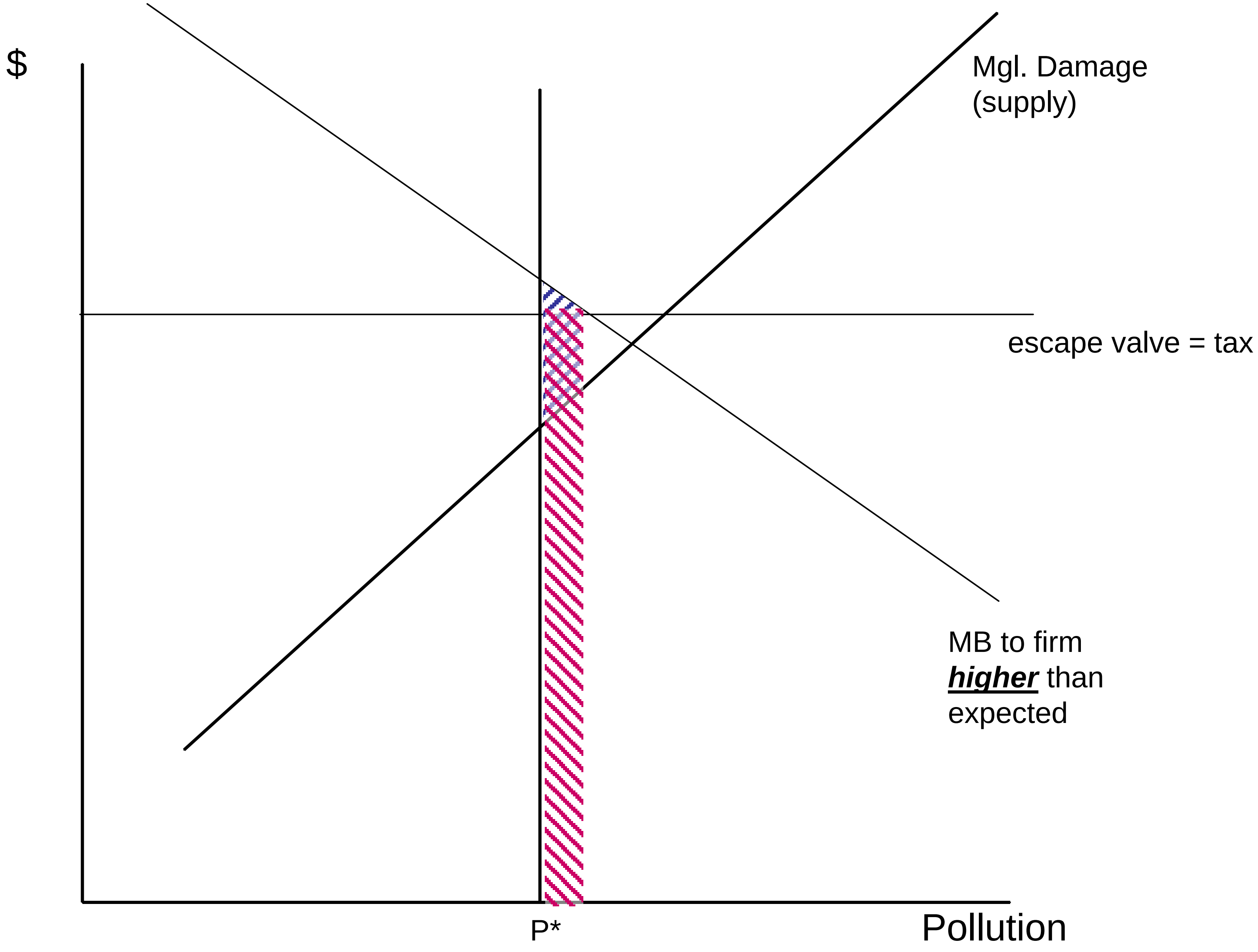
- Paper analyzes an odd policy. First we hand out permits, by sector, based on their historical *emissions* (or *value added*). Then we allow trading of emissions permits. Then we periodically update the permit allocations based on *output*.
  - Why not allocate to firms in the first place, rather than by sector. Then there's no issue about whether or not to allow inter-sectoral trade?
- First best = auction permits.
  - Problems.
    - Political feasibility

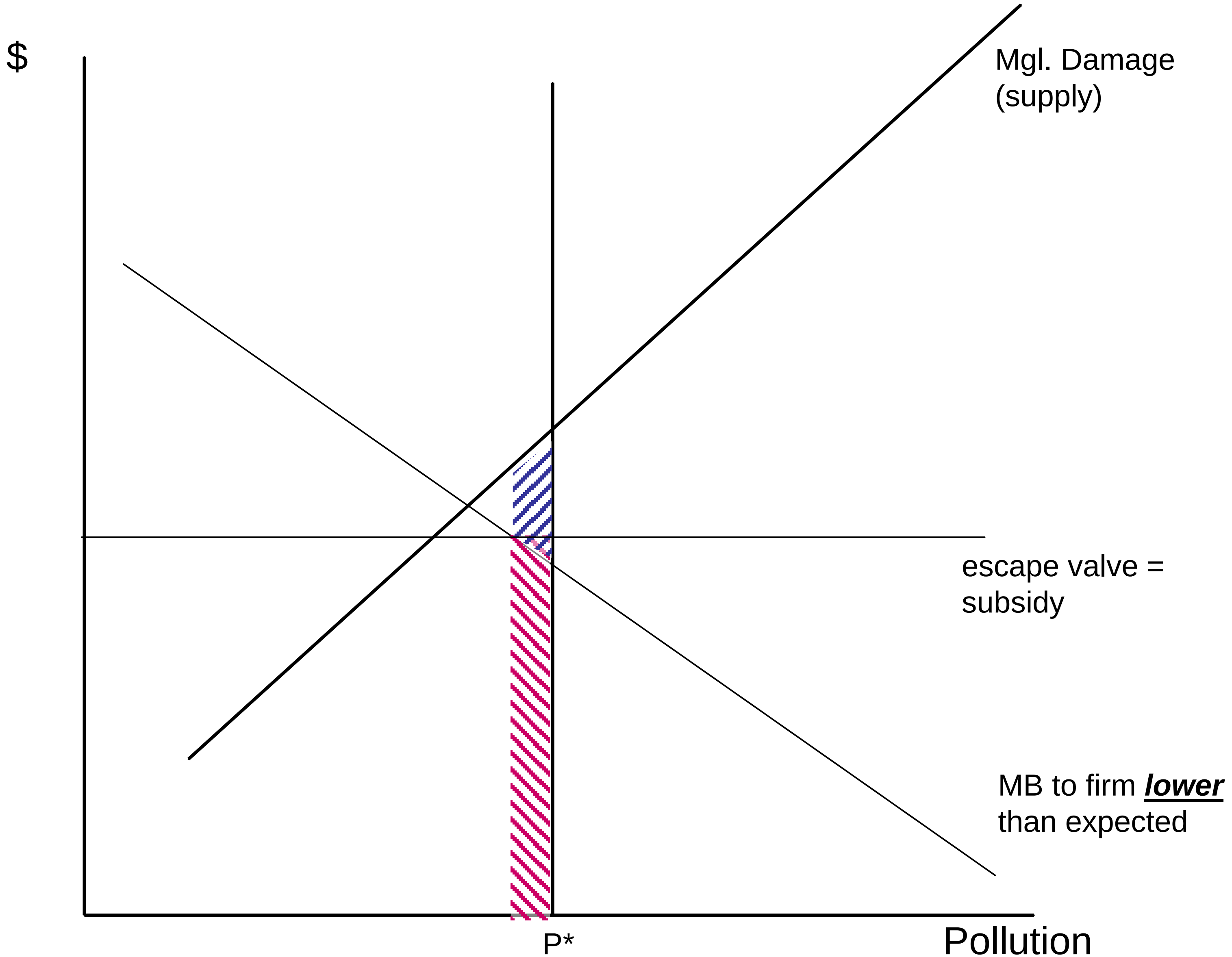
        - Tax interaction effects in 2nd best world. (Raises cost of goods, lowering real wage, increases DWL from labor tax.)
        - Leakage. (High price of goods encourages substitution for sectors or countries not regulated.)
- Second best = give away the permits to firms.
    - Among methods to give away: grandfather (lump sum) or adjust (OBA). I would have thought grandfather=2nd best and OBA=3rd best.
        - grandfather solves political feasibility, but not tax interaction/leakage.
        - OBA subsidizes output, lowers mkt price of good, reduces tax interation and leakage
            - but raises mgl abatement cost (we're not abating in least-cost way -- by reducing output), raises production cost.

Notes for Fischer/Fox

- Sensitivity analysis. Do table 3 (or 12 or 13) under a variety of scenarios:
  - change assumptions about labor elasticity or hours in the day, etc. tax rates, etc.
  - (More of figures 3 and 4.)
- p. 6. Define "performance standards" earlier, and more clearly.
- Why would you hand out permits by sector? I.e. output based or VA based or historical emissions based permits could be handed out (and adjusted) on a firm-by-firm basis. Or define the whole economy as one sector.
- Figure 1 took me some time to figure out. The paragraph on p. 12 is pretty cryptic. Why the first part of DWL" the higher-than optimal production costs"? Because firms have produced more, and therefore need to employ more costly abatement techniques in order to reduce their emissions rates? Doesn't that come with an associated benefit, in the form of cleaner air? That should lower the externality and reduce that line, but I see after some puzzling that total damage is the same at both output levels, because total emissions are capped.
- p.12, "It is worth noting that applying separate cap and trade programs with output-based allocations to multiple sectors is equivalent to setting performance standards." Why? By "performance standards" do you mean ratios of emissions per unit output?
- Why is thinking about trading across sectors in a multisector market different than thinking about trading across firms within a sector? Firms within a sector have different cost structures, emissions, and demand elasticities (all the things that make trading cost-effective). I guess this is the same as asking why not just have overall allocation by historical emissions or value added, then allow trade. I.e. just define the whole economy as one sector.
- Top of p. 14, say explicitly whether sector 1 buys or sells permits. (I confess it took me more than a minute to figure out.)
- Other papers that model emissions permits based on outputs (or inputs)
  - Oates and Schwab JPubE (1988) pollution allowed (non-tradable) based on labor.
  - Fullerton and Heutel (2005). "The General Equilibrium Incidence of Environmental Mandates" (Study incidence of regulation that affects emissions per unit of output in Harberger Framework.)
- The differences in table 12 seem extraordinarily small. (<3% of the damages from one hurricane, as you note). They seem well within any errors in the CGE model.
  - That said, the amounts (as opposed to percentages) are significant. Is it truly the case that OBE will always dominate grandfathering, or can you input parameters where the orderings in figure change. (Looks like it does from the undiscussed figures 3 and 4.

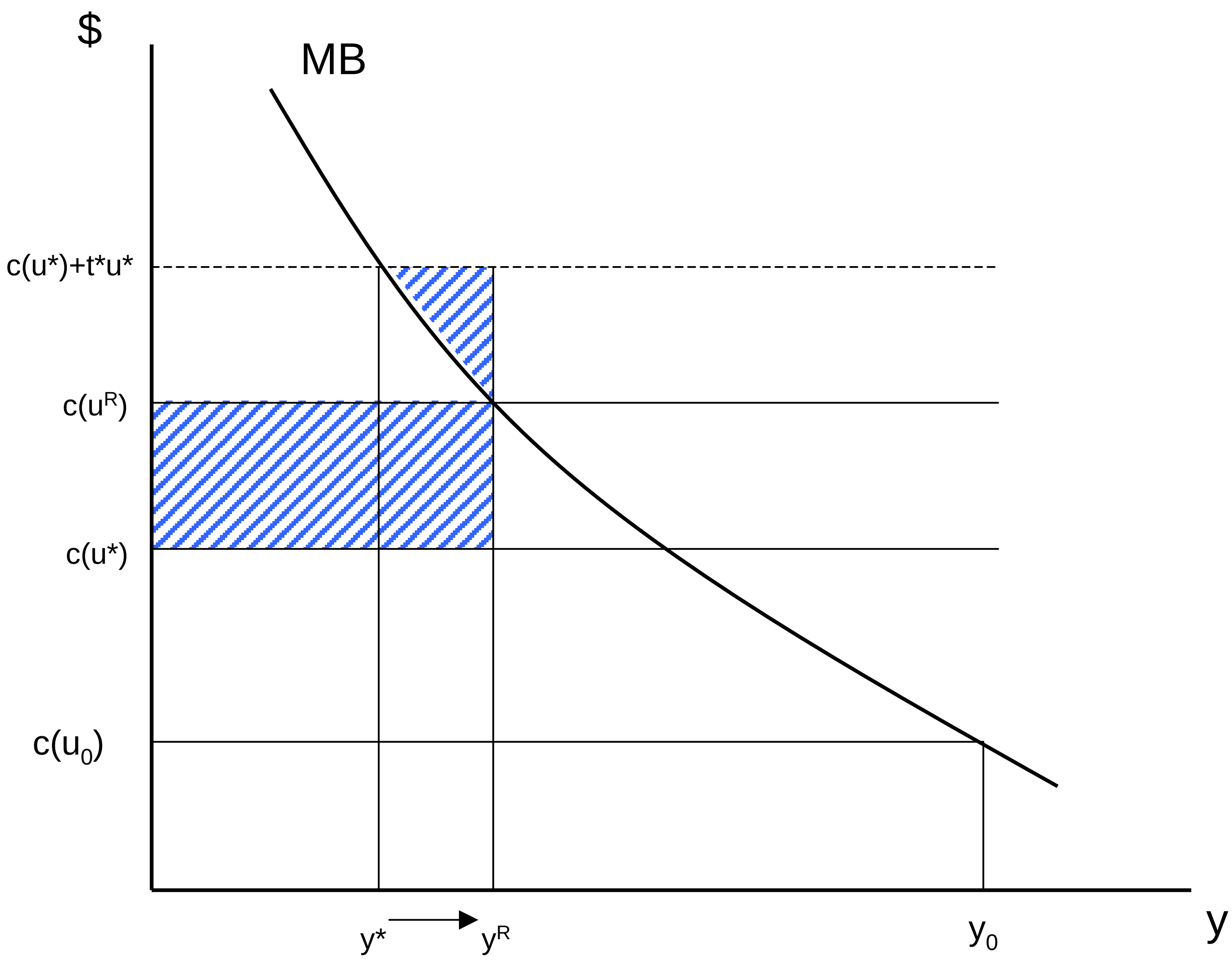
Burtraw, Kahn, and Palmer

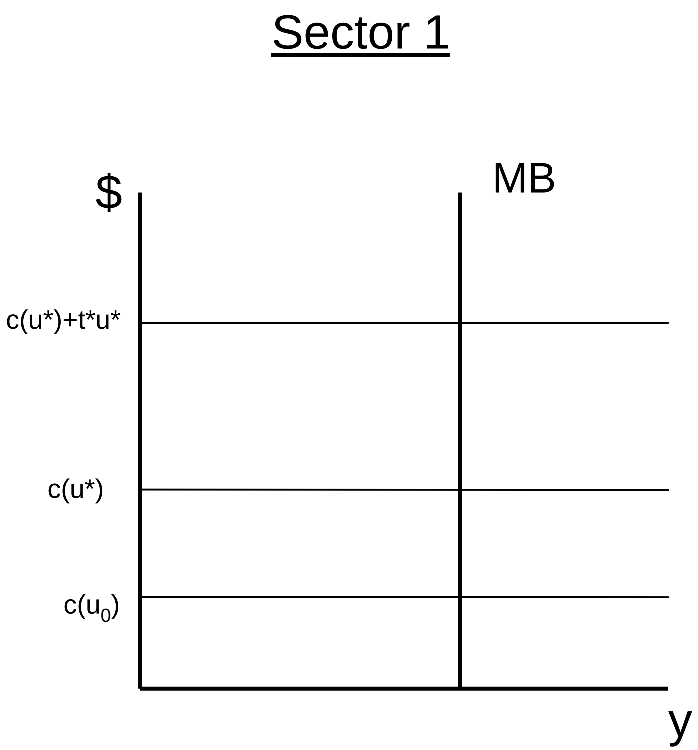


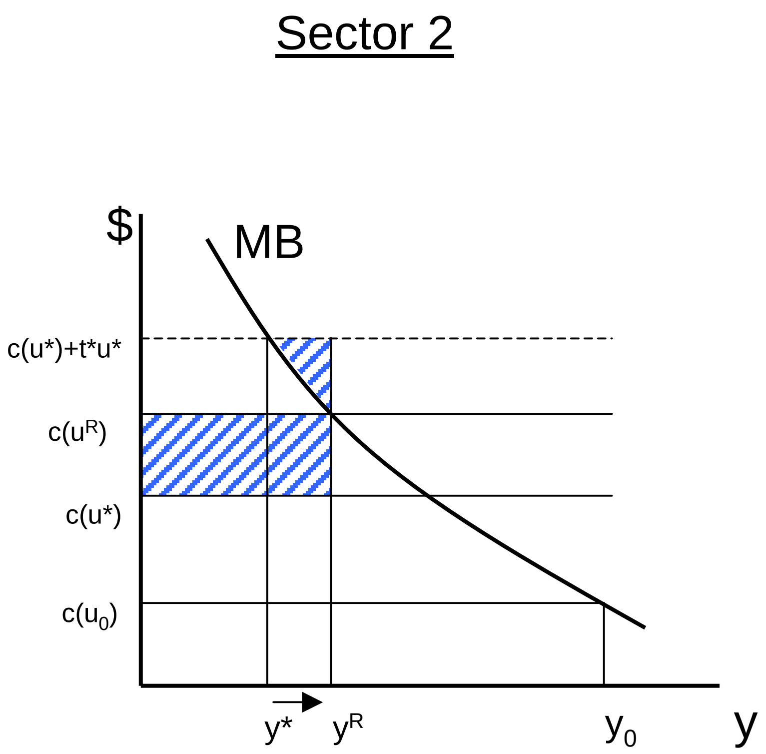


$
Mgl. Damage
(supply)
escape valve =
subsidy
MB to firm ***lower***
than expected
P*
Pollution

Fischer and Fox -- Figure 1







- consumers get 100% output subsidy
- no efficiency loss
- $u^R = u^*$
- $c(u^R) = c(u^*)$

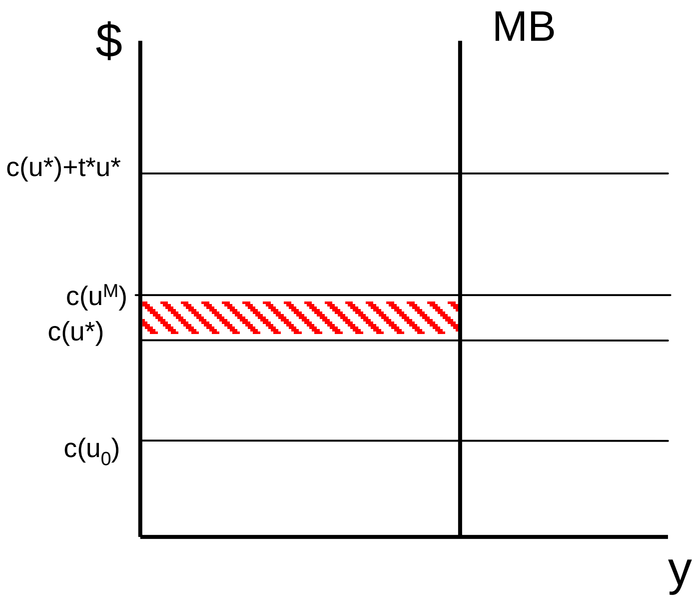
- output subsidy
- efficiency loss
- $u^R < u^*$
- $c(u^R) > c(u^*)$

$$c'(u_1) < c'(u_2)$$

Allow Trading Across Sectors

Sector 1

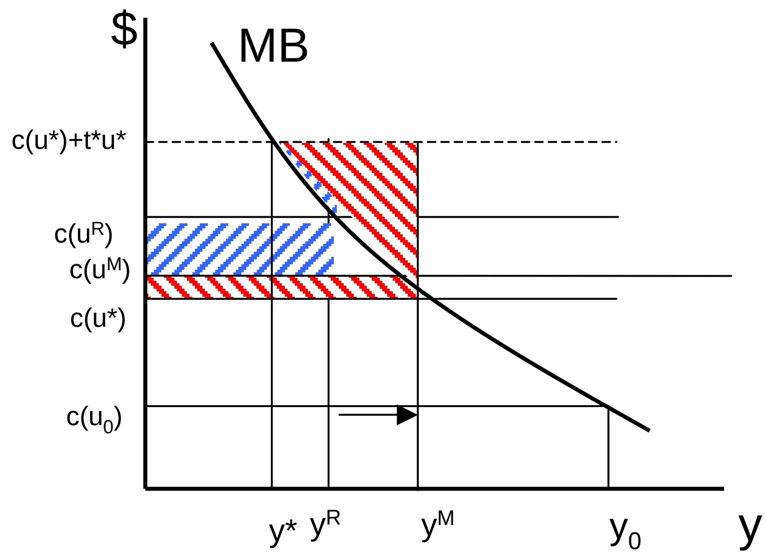
•sells permits, passing compliance cost to customers



•consumers get less of the output subsidy
•Sector 1 shares some of the efficiency loss
•$u^M < u^*$
•$c(u^M) > c(u^*)$

Sector 2

•buys permits, to reduce compliance cost of extra output



•increased output subsidy
•efficiency loss changes
•$u^R < u^R < u^*$
•$c(u^R) > c(u^R) > c(u^*)$

Question before turning to CGE

• Relabel "sectors" as "firms" and we're back to a case against trading in the first place.

• We might as well partition the market by region, or alphabetically.

• Why the arbitrary division of the permit market into sectors?

- McCain-Lieberman Act?
- GTAP model constraints?

• Amounts to an diminution of the gains from trading permits.

The CGE Model

GTAP + energy (GTAP-EG) + carbon + labor/leisure

Many assumptions.

- labor income tax rates 40% and 20%
- uncompensated labor supply elasticity 0.1
- benchmark elasticity of subst. between labor and leisure 1.736 in US
- policy goal reduce CO_2 by 14%
- no caps in other countries (maximize leakage)
- energy CES nested to three levels
- ...
- ...
- ...
- ...

Table 12: Summary Indicators for the United States

Indicator	*Unit*	*Auction*	*Grandfather*	*Hist. OBA*	*VA OBA*
Welfare	% change in equivalent variation	0.00	-0.05	-0.04	-0.01
Production	% change	-0.38	-0.54	-0.36	-0.42
Employment	% change	0.12	-0.15	0.00	0.03
Real wage	% change	0.46	-0.59	-0.02	0.09
Labor tax change	percentage pts	-1.81	0.00	-0.34	-0.40
Carbon leakage	% of reductions	15.4	15.3	12.5	15.3
Permit price	$/metric ton C	$49.21	$48.59	$70.47	$49.87

1. VA OBA *is* auctioning.
2. Differences small, given uncertainties in CGE.

Insights

- OBA not necessarily worse that grandfathering

- Trading among sectors not necessarily more efficient.