When Revenue Recycling Isn't Enough: Permit Allocation Strategies to Minimize Intra- and International Emissions Leakage

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Key Words: emissions trading, output-based allocation, tax interaction, carbon leakage

JEL Classification Numbers: Q2, Q43, H2, D58, D61

Initial Draft – Please Do Not Quote Without Permission

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Carolyn Fischer and Alan K. Fox*

Introduction

Among U.S. policy makers, an important criticism of the Kyoto Protocol, the international agreement to reduce emissions of the greenhouse gases that cause global climate change, is the lack of binding emissions targets for major emitters among developing countries. In particular, energy-intensive industries worry that a policy (like a cap-and-trade program for CO_2) that levies a price on domestic emissions alone will distort the playing field with their competitors in nonparticipating countries. Policymakers express concern that such trade impacts will result in a partial undoing of their efforts to reduce emissions, known as "carbon leakage."

Nor is leakage strictly an international phenomenon. Distortions also can arise within the domestic economy if the environmental policy is unevenly applied, due to technical, administrative, or other concerns. Sectors covered by the cap-and-trade program may fear a reallocation of resources toward the uncovered sectors, which would then also require additional or more stringent regulations.

Bernard et al. (2007) show that such inefficient reallocations can be prevented by taxing the unregulated sectors, according to the emissions embodied in their output. However, when

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unregulated sectors reside abroad, such a tax may be prohibited by WTO rules and, in any case, would only apply to imports, not to all the unregulated production. Among domestic unregulated sectors, such a tax would be as difficult to implement as a full downstream emissions trading program. Barring such a tax, they show that the next best policy is to subsidize the output of the regulated sectors. The optimal subsidy then reflects the value of the emissions crowded out by additional output in that regulated sector.

One way of implementing such a subsidy in a traditional emissions cap-and-trade program is by updating the allocation of permits to firms within the affected sectors based on their output (which we will refer to as “output-based allocation” or OBA). The value of additional permits represents an incentive to produce more, offsetting part of the price increase induced by the emissions regulation itself. Another way is by setting performance standards; in this case, each sector must meet an average emissions requirement. The effect is in theory identical—each firm must surrender permits according to its emissions and receives an allocation according to its output. However, in practice it is difficult to set performance standards such that marginal cost equalization is met, unless the permits are also tradable across sectors, and it is more difficult to ensure that a particular emissions target is met.

These mechanisms have been of interest in researchers concerned about pre-existing tax distortions. Labor taxes distort the consumption-leisure tradeoff, and environmental regulation that further raises consumer prices exacerbates those costs (a collection of the literature is available in Goulder 2002). Since the output subsidy embodied in performance standards limits those price increases, these mechanisms can outperform a system of grandfathered emissions permits (Goulder et al. 1999, Parry and Williams 1999, Fullerton and Metcalf 2001).

In an international context, trade distortions can be as important as tax distortions: while all domestic sectors are covered by the emissions trading program, trade partners are not covered, which allows carbon to “leak” as production shifts to unregulated producers. Fischer and Fox (2007) consider the effects of different allocation mechanisms, including output-based allocation, on the efficiency and distributional effects of a carbon emissions trading program in the U.S., when both tax and trade distortions are taken into account. They find that the output subsidies implicit in OBA mitigate tax interactions, which can lead to higher welfare than grandfathering. However, the rule for determining the sector allotments, which determines the effective output subsidy, matters. OBA with sectoral distributions based on value added generates effective subsidies similar to a broad-based tax reduction, performing nearly like auctioning with revenue recycling, which generates the highest welfare. 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. Importantly, they also find that industry production and trade impacts among less energy-intensive sectors are also shown to be quite sensitive to allocation rules.

We focus on two major examples that can justify support for output: (1) imperfect participation and (2) tax interaction.

Imperfect participation occurs when the environmental program exempts significant portions of an industry—for example, small producers, or sectors in which monitoring is more difficult (like nonpoint sources), or sectors outside the jurisdiction of a regulator (like foreign producers of a global pollutant). 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. (2007) 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.

This paper analyzes tradeoffs in choosing different allocation mechanisms in order to achieve overall emissions reductions goals while minimizing intra- and international leakage and minimizing the traditional measures of welfare loss associated with emissions reductions. It expands on the preceding literature in two important ways. First, it allows for leakage among domestic sectors, by dividing the economy into sectors that are more likely to be covered under an emissions trading program and those that would remain uncovered. Second, it assumes the policy goal is to meet a net emissions constraint—that is, to ensure true reductions, net of leakage—rather than a simply domestic emissions constraint. This assumption helps judge the true welfare costs and sectoral impacts of reducing global emissions.

To lend greater currency to the analysis, reductions will be considered in the spirit of recent proposals for a domestic cap-and-trade program for CO2, such as the *Climate Stewardship Act of 2003,* co-sponsored by Senators John McCain and Joseph Lieberman, and also reflecting trends in sectoral coverage that have emerged in the European Emissions Trading System (ETS). The goal of the paper is to uncover certain rules for identifying sectors and mechanisms for minimizing the costs of broader emissions reduction when considering the interaction of one country's emissions policies with unregulated emissions and labor market distortions in other countries.

The analysis is carried out in a modified GTAP framework augmented with a labor-leisure choice. Such a framework allows for the consideration of how distortionary tax instruments may be offset by revenues generated from permit auctions or may be exacerbated by policies that raise prices. The current implementation employs the GTAP version 6 (Release Candidate) database.

Once the covered sectors have been defined and the total cap is set, gratis allocation of emissions permits in a multi-sector cap-and-trade program effectively occurs in two phases, and both matter. In the first phase, a decision is made about how the total cap is apportioned among the sectors; we consider historical emissions and historical value-added shares as examples. In the second phase, a decision is made about how the sector-level cap is allocated; here, we consider grandfathering (lump-sum allocation) and output-based allocation (updating). When OBA is chosen in the second phase, the first-phase choice of the sector-level caps determines the effective output subsidies generated by the updating of allocations at the firm level.

Our results indicate that, with domestic and international leakage, output-based allocation of emissions permits to the covered sector can dominate auctioned permits in terms of generating higher welfare, even allowing for pre-existing tax distortions. However, the strategy for setting the sector-level targets plays an important role. In particular, we found that OBA based on value-added shares cost slightly less in welfare terms than auctioning with revenue recycling, while OBA with sector-level distributions based on historical emissions shares cost more, despite its previous promise in terms of reducing leakage. Grandfathered permits generated the highest welfare costs of the policies reaching the net emissions target.

Theoretical Background

To understand the optimal tax problem, we expand upon the analysis of Bernard et al. (2007) to add a labor tax and revenue constraint. Consider a simple global economy with two countries (one with emissions regulation and one without), two goods, and two factors of production (labor and emissions). Labor is considered the third good and (without loss of generality) will be taken as the numéraire. The following list summarizes our notation:

Quantities

Q_1 = Production in the regulated sector

Q_2 = Production in the unregulated sector

L_1 = Labor demand in the regulated sector

L_2 = Labor demand in the unregulated sector

L = Labor supply

l = Leisure = 1-L

C_1 = Demand for good produced in the regulated sector

C_2 = Demand for good produced in the unregulated sector

E_1 = Emissions of pollutant in the regulated sector

E_2 = Emissions of pollutant in the unregulated sector

Prices

p_1 = Consumer prices in the regulated sector

p_2 = Consumer prices in the unregulated sector

q_1 = Producer prices in the regulated sector

q_2 = Producer prices in the unregulated sector

w = Labor wage

τ_1 = Tax on emissions in the regulated sector

t_1 = Tax on regulated commodity

t_L = Tax on labor

Specifications

The household sector comprises a representative consumer, allowing us to avoid consideration of international equity in the analysis. Utility is a function of consumption of both goods and leisure:

$$U = U(C_1, C_2, 1 - L).$$

Given the absence of labor tax distortions here, leisure could equivalently represent all clean commodities, and labor a fixed factor supply.

Households also suffer disutility as a function of total emissions:[1]

$$D = D(E_1 + E_2)\,.$$

The welfare function, then, is the difference between consumption utility and emissions disutility, which we have assumed to be separable:

$$W = U - D = U(C_1, C_2, 1 - L) - D(E_1 + E_2).$$

Production in each sector (i = 1, 2) is a function of labor and emissions: $Q_i = f_i(L_i, E_i)$. Equivalently, labor in each sector can be specified as a function of output and emissions:

$$L_i = L_i(Q_i, E_i)\,.$$

Finally, a government revenue constraint requires that

$$t_L L + t_1 Q_1 + \tau_1 E_1 + \tau_2 E_2 = G$$

We assume that the good produced by the unregulated sector is the untaxed commodity.

Decentralized Markets

It is well understood that if the social planner could choose quantities of output and emissions directly, the marginal damage of all emissions would be equalized with the cost of reducing them and the marginal value of a good's consumption would equal its social marginal

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[1] An alternative—and equivalent—formalization would be to impose a limit to total damages; the shadow price of the constraint then represents the value of the marginal damage. Simulations would then compare results given an emissions target, such as with a cap-and-trade policy, rather than given an emissions tax that equalizes marginal costs and benefits.

cost, inclusive of the externality. In the decentralized problem, the planner uses taxes to influence market prices and achieve this outcome. The maximization problems of the consumer and producers form the constraints for the planner, along with any regulatory constraint.

Consumer Problem

Taking pollution externalities as given, the representative household maximizes utility with respect to consumption and leisure,

$$U(C_1, C_2, 1-L)$$

subject to a budget constraint:

$$(\lambda) \quad p_1 C_1 + p_2 C_2 - w(1-t_L)L = 0.$$

From the consumer problem, we obtain

$$(C_1)\ \frac{\partial U}{\partial C_1} = p_1\lambda; \qquad (C_2)\ \frac{\partial U}{\partial C_2} = p_2\lambda; \qquad (L)\ \frac{\partial U}{\partial L} = -\lambda w(1-t_L).$$

Producer Problems

The representative firm in each sector *i* chooses output and emissions to maximize profits:

$$\pi_i = q_i Q_i - wL_i(Q_i, E_i) - \tau_i E_i\,,$$

from which we obtain

$$(Q_i)\ q_i = w\frac{\partial L_i}{\partial Q_i}; \qquad (E_i)\ -w\frac{\partial L_i}{\partial E_i} = \tau_i.$$

The first expression implies that the output price equals the marginal cost (or, with some rearranging, that the value of the marginal product of labor equals the wage rate). The second means that the labor cost savings from using more emissions just equal the tax.

Government Revenue

The government revenue constraint implies that any shortfall from the consumption and emissions taxes must be made up by a tax on labor:

$$G = t_1 C_1 + \tau_1 E_1 + t_L L$$

Market Equilibrium

In equilibrium, we have

$$C_1 = Q_1; \quad C_2 = Q_2; \quad L_1(Q_1, E_1) + L_2(Q_2, E_2) + G = L$$

and $q_i = p_i - t_i$, and the revenue constraint is met.

With well-behaved utility and production functions, consumption of each good is decreasing in its own costs, which include output and emissions taxes, so $dC_i / dt_i < 0$ (and $dC_i / d\tau_i < 0$). Let us define the goods as substitutes if $dC_i / dt_j > 0$ and complements if $dC_i / dt_j < 0$. These cross-price effects depend not only on the signs of the cross-partials in the utility function, but also the general equilibrium. Overall labor supply is increasing in the marginal utility of consumption.

Planner Problem

The question at hand is what happens when the policymaker cannot regulate pollution in sector 2. Two polar cases will be considered: 1) the output of the unregulated sector can be taxed (or subsidized), as can that of the regulated sector; 2) the unregulated sector must also remain untaxed, while the regulated sector can be taxed or subsidized as well as regulated.

The social planner maximizes welfare, *W*, with respect to $t_1, \tau_1,$ subject to the aforementioned constraints. The essence of the optimal tax problem can be seen by totally differentiating welfare:

$$dW = \frac{\partial U}{\partial C_1} dC_1 + \frac{\partial U}{\partial C_2} dC_2 - \frac{\partial U}{\partial l} dL - \frac{\partial D}{\partial E}\left(dE_1 + dE_2\right)$$

Using the first-order conditions from the consumer problem, this equation simplifies to

$$\frac{dW}{\lambda} = p_1 dC_1 + p_2 dC_2 - w(1-t_L)dL - \frac{D'}{\lambda}\left(dE_1 + dE_2\right)$$

Furthermore, $dL = dL_1 + dL_2$ and totally differentiating the production function, we get $dL_i = \frac{\partial L_i}{\partial Q_i} dQ_i + \frac{\partial L_i}{\partial E_i} dE_i$. Using the producer first-order conditions and market equilibrium conditions, this implies $dL_i = \frac{q_i}{w} dC_i - \frac{\tau_i}{w} dE_i$. Substituting, we get the marginal welfare impacts of the different policy levers (relative to the marginal utility of consumption):

$$\frac{dW}{\lambda} = t_1 dC_1 - \left(\frac{D'}{\lambda} - \tau_1\right) dE_1 - \left(\frac{D'}{\lambda}\right) dE_2 + w t_L dL$$

We can further simplify by noting that output taxes change emissions by crowding out (or in) output. Thus, $dE_i / dt_j = m_i dC_i / dt_j$ for all {*i,j*}, where *m* is the marginal emissions rate. Similarly, the impact on emissions in one sector of a change in the emissions tax in the other sector depends on crowding out: $dE_i / d\tau_j = m_i dC_i / d\tau_j$, for $i \neq j$. Note that since the emissions tax also impacts the emissions intensity, $dE_1 / d\tau_1 = m_1 dC_1 / d\tau_1 + C_1 dm_1 / d\tau_1 > m_1 dC_1 / d\tau_1$. Thus,

$$\frac{1}{\lambda}\frac{dW}{dt_1} = t_1\frac{dC_1}{dt_1} - \left(\frac{D'}{\lambda} - \tau_1\right)m_1\frac{dC_1}{dt_1} - \left(\frac{D'}{\lambda}\right)m_2\frac{dC_2}{dt_1} + wt_L\frac{dL}{dt_1}$$

$$\frac{1}{\lambda}\frac{dW}{d\tau_1} = t_1\frac{dC_1}{d\tau_1} - \left(\frac{D'}{\lambda} - \tau_1\right)\frac{dE_1}{d\tau_1} - \left(\frac{D'}{\lambda}\right)m_2\frac{dC_2}{d\tau_1} + wt_L\frac{dL}{d\tau_1}$$

Solving for the optimal tax by setting the welfare change equal to zero, and using the Chain Rule, we get

$$t_1 = \underbrace{\left(\frac{D'}{\lambda}\right)m_2\frac{dC_2}{dC_1}}_{\substack{\text{leakage impact}\\(-)}} + \underbrace{\left(\frac{D'}{\lambda} - \tau_1\right)m_1}_{\substack{\text{uninternalized}\\\text{per-unit damages}}} - \underbrace{t_L\frac{dL}{dC_1}}_{\text{tax interaction}} \tag{1}$$

$$\tau_1 = \underbrace{\frac{D'}{\lambda}}_{\substack{\text{marginal}\\\text{damage}}} + \underbrace{\left(\left(\frac{D'}{\lambda}\right)m_2\frac{dC_2}{dC_1} - t_1\right)\frac{dC_1}{dE_1}}_{\text{uninternalized leakage }(-)} - \underbrace{t_L\frac{dL}{dE_1}}_{\text{tax interaction}} \tag{2}$$

Solving for the optimal tax combination, we get

$$\tau_1 = \frac{D'}{\lambda}$$

and

$$t_1 = \left(\frac{D'}{\lambda}\right)m_2\frac{dC_2}{dC_1} - t_L\frac{dL}{dC_1} < 0$$

The first equation states that the optimal emissions tax equals the marginal damages. The second states that the optimal rebate has two components. First, it internalized the marginal damages of the emissions generated by the substitution of consumption away from the regulated good toward the unregulated good. Second, the rebate is needed to counteract the tax interaction problem. Thus, a subsidy to Sector 1 to prevent emissions leakage and tax interaction is preferred to full recycling of the environmental tax revenues.

Let us put these results in the context of of Bovenberg and de Mooij (1994), Fullerton (1997), Williams (2000) and others who assume that emissions have a linear relationship with output. In their case, $E_1 = C_1$ (or $m_1 = 1$), so the emissions tax would be a commodity tax. Suppose that Sector 2 is a clean good, so $dE_2 = 0$ and $m_2 = 0$. Then for the dirty good we have

$$\tau_1 = \frac{D'}{\lambda}; \quad t_1 = -t_L \frac{dL}{dC_1}$$

This combination is equivalent to their result of an optimal second-best emissions (commodity) tax being lower than the Pigouvian level by the tax interaction effect. Similarly, in this case in which technical abatement opportunities are available, if a rebate is not a policy option, we would have $\tau_1 = \frac{D'}{\lambda} - t_L \frac{dL}{dE_1}$. When a rebate is an option, though, it is a more effective means of addressing the tax interaction effects than distorting the marginal abatement incentives. Since the labor supply disincentive derives from the product price increase, a price rebate addresses the tax interaction problem directly.

Another issue for output-based rebating is how accurate 100% rebating is, which is the case of distributing all of the permits gratis according to output. The optimal rebate rate is one if the subsidy expenditures equal the emissions tax revenues:

$$C_1\left(\left(\frac{D'}{\lambda}\right)m_2\frac{-dC_2}{dC_1} + t_L\frac{dL}{dC_1}\right) = \left(\frac{D'}{\lambda}\right)E_1$$

that is, if

$$\frac{m_2}{m_1}\frac{-dC_2}{dC_1} = \left(1 - t_L\frac{dL/dC_1}{m_1 D'/\lambda}\right)$$

In the absence of a labor tax, this holds if the emissions tradeoff (leakage factor) is one-to-one, such as for two perfect substitutes with identical emissions rates. With pre-existing labor taxes, this leakage factor must be higher than one to justify 100% rebating, due to the opportunity cost of public revenues. How much higher than one depends on the relative size of the labor tax distortion to the marginal emissions damages.

More generally, with two dirty goods, it is interesting to see how additional policy constraints affect the second-best (or *n*th-best) taxes. One constraint could be on the earmarking of the allocation. If the resulting rebate is too low (high), then Equation (2) reveals that the optimal emissions price will be lower (higher) than if the leakage and tax distortions were exactly internalized.

Meanwhile, if the emissions price is too low and is restricted from fully internalizing the marginal damages, Equation (1) shows that the optimal rebate is lower, reflecting the need for taxing the emissions embodied in additional output that did not get taxed directly.

To understand the relative magnitude of these kinds of policy constraints on welfare and other measures of the burdens of regulation, we next turn to a simulation model.

Numerical Model

Model Description

We employ a modified version of the model used in Fischer and Fox (2007), in which greater descriptive detail can be found. This CGE model from the Global Trade Analysis Project (GTAP) offers a richness in calculating trade impacts that allows us to evaluate the distributional and efficiency effects of emissions permit allocation mechanisms, spanning a more diverse and disaggregated set of energy-using sectors than in most climate models. However, this model is not designed specifically to study climate policy; being a static model, 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.[2] 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. Our impacts of interest include CO2 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 5.4 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 used is a GAMS dataset merging the GTAP economic data with information on energy flows. We adapt the framework to employ the latest available GTAP database, Version 6.0 Release Candidate, which updates the analysis to 2001, the base year of the latest GTAP database. 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 their corresponding carbon emissions are

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[2] In the default, capital reallocation occurs within, not across, regions. Paltsev (2001) conducts sensitivity analysis with respect to this assumption and finds that the carbon leakage rate to does not change significantly with greater international capital mobility.

incorporated into this framework. The production function incorporates most intermediate inputs in fixed proportion, although energy inputs are built into a separate energy nest. For the chemicals sector, which includes petrochemicals, we divided its energy use into feedstock requirements, which are treated as intermediate inputs, and the remainder, which is treated as energy, using the feedstock use ratios for oil and gas in Lee (2002). 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, in our modification, leisure. 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 in Fischer and Fox (2007) and Fox (2002).

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 that is applied to the covered sectors. 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, allowing us to conduct simulations recycling revenue from pollution permits to offset the distorting tax instrument. Since we have no data on labor taxes within the GTAP-EG database, we assume a labor tax rate of 40 percent within Annex B countries and a 20 percent tax rate within all other countries and the Rest of World.

To incorporate the pollution permit requirement, we introduce the carbon permit as a Leontief technology in an additional composite fossil fuel nest to production in the covered sectors (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). In this manner, one permit is demanded for each unit of carbon that enters into production, and we can track pollution permits through the model.

To model output-based allocation, we incorporate a distortion in the form of an endogenous tax into the sector's production function. This tax allows us to mimic the impact on the firm of an output-based subsidy. The value of the subsidy is determined by constraints that establish the carbon price and the per-unit allocation. The MPSGE representation of these modifications can be found in Appendix A.

Policy Scenarios

Sector Coverage

We consider a scenario in which the U.S. adopts an emissions trading program similar in form to the European ETS in terms of its sector coverage (although we assume unilateral implementation). This scenario follows the general outline of the cap-and-trade scheme found in the *Climate Stewardship Act of 2003,* S.139, hereafter referred to by the names of its co-sponsors, Senators John McCain and Joseph Lieberman.[3] McCain Lieberman treats a much broader spectrum of airborne pollutants, but this paper will concern itself only with CO_2 emissions. Like most proposals for a domestic trading system, McCain-Lieberman foresees that only major point source emitters (in their case, those responsible for more than 10,000 metric tons of CO_2 , or about 2,700 metric tons of carbon) are subject to a cap-and-trade system. We model this as a simple carbon permit requirement on the use of all final energy goods in the model—coal, refined petroleum products, or natural gas. Unfortunately, our database only provides information on the size of sectors, not on the size of individual firms with those sectors. We therefore assume that the covered sectors are covered in their entirety. The sectors subject to the cap are

- electricity
- petroleum and coal products (refined);
- iron and steel industry;
- chemical industry;
- non-metallic minerals (which include cement, glass and ceramics); and
- paper, pulp, and print.

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[3] For a more complete analysis of McCain-Lieberman, see Pizer and Kopp (2003).

This assumption overstates somewhat the magnitude of covered pollution, depending on the distribution of firm size within each of these sectors. On the other hand, it might also understate coverage somewhat if some firms outside these sectors would be included in the regulation. These sectors represent 55% of U.S. CO_2 emissions, according to the data.

Since our focus is on understanding the role of leakage in policies that target a limited set of sectors, we exclude transportation fuels. This assumption represents a departure from McCain-Lieberman, who propose that carbon emissions originating from transportation fuels such as gasoline, diesel, and jet fuel would also generate a permit liability. However, few other recent proposals have included the transportation sector,[4] nor does the EU ETS. Furthermore, our model and database lack the sectoral and commodity detail to permit analysis by fuel type.

Defining the Cap

We set, somewhat arbitrarily, the basic policy goal to be equivalent to a 20% reduction of CO_2 emissions for the covered sectors from the base-year level (2001 in our case). All further references to pollution in this paper are to the carbon equivalent of these CO_2 emissions. This target, all else equal, would result in a 11% reduction in domestic emissions, and it is within the range of several policy proposals with goals to reduce emissions by 2010.[5]

Initially, we require all policy scenarios to meet this target reduction only in the covered sectors. However, with leakage, the benefits of each policy will vary, due to the different net reductions in emissions. Later, to simplify welfare comparisons, we conduct sensitivity analysis

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[4] A few proposals do target upstream fuel suppliers, which would provide more comprehensive coverage: S.A. 868 (Bingaman) and H.R. 5049 (Udall).

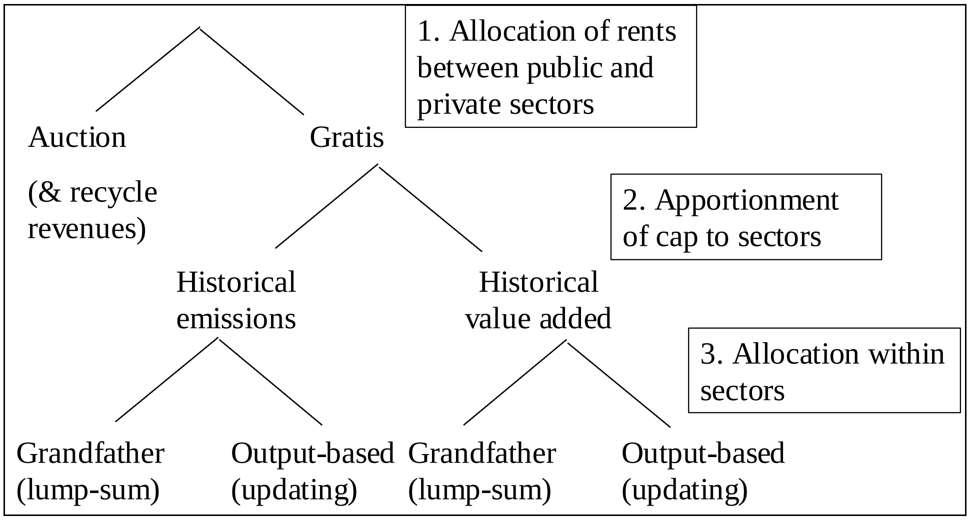
[5] The McCain-Lieberman Climate Stewardship Act of 2003 proposes to cap emissions in 2010–2016 to 2000 levels, eliminating a decade of increase. After that period, emissions are to be further reduced to 1990 levels, though not below, as specified in the Kyoto Protocol targets.

requiring all policy scenarios to meet this target reduction net of carbon leakage to other sectors and other countries.

Permit Allocation

In effect, three sets of decisions are required to structure the allocation of emissions permits, which we illustrate in the following Figure. First, one decides whether they will be auctioned or distributed gratis. For the gratis distribution scenarios, permit allocation requires two additional tiers of decisions. 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 2.) 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.

Figure 1: Tiers of Allocation Decisions



We consider a total of four combinations of these allocation decisions to explore the implications of allocation mechanisms in a carbon cap-and-trade program:

Auction: All permits are sold—no gratis distribution.

Grandfather: Permits are distributed unconditionally among firms in all covered sectors (except final demand). This is the equivalent of a lump-sum rebate of all permit revenues. The sector-level apportionment determines the distribution of the rents but does not affect behavior.

OBA/Emissions: Allocations to firms in covered sectors are updated based on output shares within their sector. At the sector level, caps are based on historical emissions.

OBA/Value-Added: Allocations to firms in covered sectors are updated based on output shares within their sector. Sector shares are based on historical shares of value added.

In all cases, permits are traded across the covered 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.[i]

Numerical Results

When the cap-and-trade program is limited to the above energy-intensive sectors, we find a striking result supporting the theory: even with labor tax distortions, auctioning permits to the covered sector and recycling the revenues is *not* the dominant strategy. Rather, output-based allocations with a value-added rule for sectoral distributions proves less costly. It minimizes changes in overall production, employment and the real wage. Furthermore, OBA/VA generates more true reductions, limiting leakage to a greater extent than any other strategy.

Table 1: Percentage Change in Summary Indicators

Indicator for United States	*Auction*	*Grandfather*	*OBA/ Emissions*	*OBA/ VA*
Welfare (equivalent variation)	-0.016	-0.078	-0.060	-0.014
Production	-0.28	-0.46	-0.23	-0.28
Employment	0.08	-0.22	-0.02	-0.01
Real wage	0.30	-0.87	-0.12	-0.05
Labor tax change (percentage points)	-1.16	0.84	0.05	-0.06
Carbon leakage (% of reductions)	9.4	8.7	10.8	6.5
Permit price ($/metric ton C)	$60.81	$60.21	$94.91	$68.78

Other results are consistent with Fischer and Fox (2007): Auctioning raises the real wage and employment. Grandfathering is the most costly policy in welfare terms in these kinds of second-best situations and causes the largest contraction in production and employment. OBA raises the marginal cost (permit price) of emissions abatement, since fewer reductions arise from output substitution, and this effect is most striking under OBA/Emissions. However, output substitution through trade is less cost-effective when one cares about net global emissions reductions, not just reductions in the domestic covered sectors.

The leakage result is perhaps the most surprising, since Fischer and Fox (2007) found that with full coverage in a cap-and-trade system, OBA/Emissions was more effective at limiting leakage, yet here it actually induces the most. When the covered sectors are more limited, the implicit allocation subsidy is less well targeted to the sectors that need it: the trade-sensitive, emissions intensive ones.

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

Distributional Impacts

Allocation

Table 2 reports the sector allocations for the gratis allocation options of historical emissions vs. historical value added. It reveals that, even among the energy intensive sectors, the distribution of emissions is quite different from that of value added. For example, the electricity sector accounts for three-quarters of covered emissions, but only one-fifth of value added, while the chemical, minerals and paper industries have much higher ratios of value added to emissions.

Table 2: Sector Shares of Carbon Cap with Historical Emissions and Value-Added Rules

Sector	**Emissions**	**Value-Added**
Electricity	75.0%	19.3%
Petroleum and coal products (refined)	15.3%	0.7%
Chemical industry	5.1%	39.2%
Non-metallic minerals	1.8%	8.4%
Paper-pulp-print	1.6%	25.2%
Iron and steel industry	1.2%	7.2%
Total permits allocated	**827,614**	**827,614**

These allocation differences drive many of the subsequent results of output-based allocation, but they also represent key distributional effects in themselves. Of course, these 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, and the sector allocation shares are an indicator of benefits to consumers of those industries.

Domestic Emissions

Table 3 shows the distribution of carbon emissions and reductions across both the covered and uncovered sectors in the U.S. economy. It reveals not only the distribution of effort among the covered sectors, which represent 55% of total baseline emissions, but also the impact on emissions of the uncovered sectors as well.

Table 3: Percentage Change in Emissions by Sector and Baseline Emissions

Sector	*Auction*	*Grandfather*	*OBA/ Emissions*	*OBA/VA*
Electricity	-23.4	-23.4	-23.9	-23.6
Petroleum and coal products (refined)	-8.6	-8.7	-6.3	-8.9
Chemical industry	-11.2	-11.2	-10.6	-7.7
Non-metallic minerals	-16.0	-15.9	-18.0	-14.4
Paper-pulp-print	-10.8	-10.9	-10.5	-8.8
Iron and steel industry	-9.3	-9.3	-8.8	-8.8
Covered Sectors	*-20.0*	*-20.0*	*-20.0*	*-20.0*
Other industry	-2.5	-2.6	0.8	-2.4
Primary Energy	-2.5	-2.6	-1.7	-2.8
Services (excl. transport)	0.0	0.0	0.0	0.0
Transport	-2.6	-2.7	-0.6	-2.6
Final Demand	0.6	0.4	-0.4	0.2
Uncovered Sectors	*-1.4*	*-1.6*	*-0.4*	*-1.6*
Total	**-11.6**	**-11.7**	**-11.1**	**-11.7**

Among the covered sectors, the allocation regime affects the distribution of effort, but obviously not the total reductions. We see that auctioned and grandfathered permits induce nearly identical reductions across all sectors. OBA/VA is also quite similar, but a slight increase in the reduction rate in the electricity and refining sectors allows other smaller covered sectors to reduce their effort more substantially. OBA/Emissions, however, generates quite different effects. The electricity and nonmetallic minerals sectors increase their effort, relative to the other covered sectors, while the refining sector reduces its efforts substantially. Although the electricity sector gets the largest subsidy in this scenario, the dramatic rise in the price of permits causes it to cut back its emissions even more. This effect will be better understood with the discussion of the fuel price effects.

Emissions in the uncovered sectors also respond, due to several forces in the general equilibrium that may push in different directions. First, as goods from covered sectors become more expensive, consumers may substitute toward other domestic goods. Second, to the extent uncovered sectors use energy intensive goods as inputs, domestic goods in the uncovered sectors may become more expensive relative to foreign competitors. Third, fuel prices adjust, which also affects input costs to the uncovered sectors, both here and abroad, and affects their fuel choices. And fourth, as domestic price rise, demand may contract. This combination of changes in production and fuel input usage together affects emissions in the remainder of the economy.

Auctioning, grandfathering, and OBA/VA all induce the uncovered sectors—with the exception of final demand—to reduce their emissions as well, although not as much as if they also faced a carbon price. OBA/Emissions scenario disproportionately rebates to electricity and refined petroleum products, causing the uncovered sectors to increase their consumption of these goods, limiting reductions in the rest of the economy.

Production

Table 4 gives the baseline value of production and the percentage change among the covered sectors, the transportation sectors, and the rest. Compared to grandfathering, an auction induces smaller reductions in output, due to the revenue-recycling effect that boosts the real wage, labor supply, and demand. Among the uncovered sectors, auctioning generates the smallest impact on production.

Table 4: Baseline Production and Percentage Changes by Scenario

Sector	*Baseline (billions $2001)*	*Auction*	*Grand-father*	*OBA/ Emissions*	*OBA/ VA*
Electricity	258	-7.3	-7.4	-1.4	-6.0
Petroleum and coal products (refined)	146	-5.3	-5.4	-1.4	-5.2
Chemical industry	716	-1.3	-1.5	-0.4	2.7
Non-metallic minerals	127	-1.0	-1.1	-0.3	1.7
Paper-pulp-print	392	-0.3	-0.5	-0.2	2.0
Iron and steel industry	143	-0.7	-0.9	-0.4	0.0
Covered sectors	*1,782*	*-2.2*	*-2.4*	*-0.6*	*0.3*
Other industry	3,763	-0.1	-0.3	-0.2	-0.7
Primary Energy	122	-6.1	-6.1	-5.8	-6.4
Services (excl. transport)	11,617	0.0	-0.1	-0.1	-0.1
Transport	670	-2.1	-2.6	-1.1	-2.9
Uncovered Sectors	*16,172*	*-0.1*	*-0.2*	*-0.2*	*-0.3*
Total	**17,953**	**-0.3**	**-0.5**	**-0.2**	**-0.3**

OBA, by creating an implicit subsidy, lessens the impacts on production among the covered sectors. OBA/Emissions dramatically reduces the impact on the electricity and refining sectors, and thereby also the primary energy and transport sectors, inducing the smallest overall contraction. OBA/VA actually allows covered sector output to expand, particularly among the higher-value energy intensive sectors, largely at the expense of the uncovered sectors.

Employment

In the general equilibrium, several forces drive changes in employment by sector. Among the covered sectors, the decrease in emissions leads to a substitution away from energy inputs and toward labor and capital, tending to increase labor demand. Among all sectors, changes in output tend to change labor demand. Furthermore, changes in the after-tax real wage also have employment impacts across the economy. Thus, in employment, we see some sectors increasing their labor demand, while others decrease.

Table 5: Baseline and Percentage Change in Labor Demand by Sector

Sector	*Baseline Labor Demand (billions $2001)*	*Auction*	*Grand-father*	*OBA/ Emissions*	*OBA/VA*
Electricity	25	-0.1	-0.6	9.3	1.9
Petroleum and coal products (refined)	2	6.2	5.8	14.1	7.2
Chemical industry	106	-0.5	-0.8	0.3	3.5
Non-metallic minerals	27	-0.1	-0.3	0.7	2.7
Paper-pulp-print	76	0.2	-0.1	0.2	2.5
Iron and steel industry	29	0.4	0.2	0.4	1.1
Covered Sectors	*264*	*-0.1*	*-0.4*	*1.2*	*2.8*
Other industry	665	0.1	-0.2	-0.1	-0.6
Primary energy	14	-10.2	-10.3	-10.1	-10.6
Services (excl. transport)	3371	0.1	-0.2	0.0	0.0
Transport	152	-0.2	-0.5	-0.2	-0.4
Uncovered sectors	*4196*	*0.1*	*-0.2*	*-0.1*	*-0.2*
Total	**4467**	**0.08**	**-0.22**	**-0.02**	**-0.01**

Auctioning, by raising the real wage, causes employment to expand slightly in the uncovered sectors, more than offsetting the slight contraction in the covered sectors. Grandfathering causes employment to fall across the board, with the exception of the refining and steel industries, where the substitution effect always seems to dominate. Both OBA scenarios increase employment in the covered sectors, roughly according to the major beneficiaries, with the largest expansion from OBA/VA.

Efficiency and Effectiveness

Prices

Table 6 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, petroleum products burn fossil fuels in order to make the product, and to this extent, permit requirements are reflected in the producer price. Producers in the covered sectors face energy costs that include permit costs as well as the producer price. Other producers and consumers face prices exclusive of permits, since they do not bear that requirement. For consumers of electricity, permit costs become embedded in the electricity price, as do any subsidies from an OBA. Crude oil is only used by the petroleum industry.

Table 6: Percentage change in energy prices

Sector	*Auction*		*Grandfather*		*OBA/Emissions*		*OBA/VA*	
	Excl.	*Incl.*	*Excl.*	*Incl.*	*Excl.*	*Incl.*	*Excl.*	*Incl.*
Petroleum & coal products (refined)	5.0	22.5	5.1	22.3	0.9	29.2	5.1	24.8
Natural gas	-1.4	28.1	-1.4	27.8	-1.5	45.0	-1.5	32.3
Coal	-16.6	98.5	-16.4	97.3	-17.8	162.8	-17.0	113.8
Crude oil	-1.8		-1.7		-0.6		-2.1	
Electricity	12.0		11.9		-0.5		10.1	

These results also echo Fischer and Fox (2007): For all primary energy producers, the prices received are lowest and consumer prices highest with Emissions OBA, due to the higher permit price. Electricity prices, however, rise significantly in all but the Emissions OBA scenario, in which 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.

The fall in natural gas prices helps explain the increase in emissions from final demand. Interestingly, the decrease in electricity prices with OBA/Emissions seems to prevent consumers from substituting toward polluting fuels, reducing emissions from final demand in that scenario. However, the relatively low price of petroleum products under OBA/Emissions raises emissions from the transportation sector, relative to the other scenarios.

Trade

Table 7 shows the change in net exports by sector, which is an indicator of leakage (though carbon leakage also depends on the emissions rates of the foreign competitors).

Table 7: Change in Net Exports (millions of $2001)

Sector	*Auction*	*Grandfather*	*OBA/ Emissions*	*OBA/VA*
Electricity	-761	-746	21	-698
Petroleum and coal products (refined)	-2585	-2515	-564	-2984
Chemical industry	-5394	-5173	-1207	12050
Non-metallic minerals	-923	-913	-143	2062
Paper-pulp-print	-513	-482	-188	3830
Iron and steel industry	-719	-718	-104	986
Covered Sectors	*-10894*	*-10547*	*-2185*	*15246*
Other industry	551	261	-2465	-18750
Primary Energy	8005	8113	4781	7326
Services (excl. transport)	1895	1852	-375	-3993
Transport	-798	-757	-337	-2787
Uncovered Sectors	*9653*	*9469*	*1605*	*-18203*
Total	**-1241**	**-1078**	**-579**	**-2957**

Auctioning and grandfathering have similar effects, with the net export position of the covered sectors and the transport sector deteriorating, while the position of other industries improves. In comparison, the OBA scenarios are better at mitigating these impacts for the covered sectors, at some expense to the uncovered sectors. However, we see a striking difference between the two OBA regimes. OBA/Emissions actually increases net exports of electricity in absolute terms and boosts refined petroleum products relative to the other scenario, due to the strong implicit subsidy for these sectors. Meanwhile, value-added OBA boosts the net exports of the other energy-intensive sectors substantially, while reducing the net exports of the remaining sectors. An exception is the primary energy sector, which increases its net exports in all scenarios, due to declining domestic demand.

Carbon Leakage

Table 8 shows total carbon leakage by sector in 1000 MT C. Among the covered sectors, the leakage is strictly from foreign firms; among the uncovered sectors, leakage equals the net change in emissions at home *and* abroad.

Table 8: Composition of Carbon Leakage (Foreign and Domestic) by Sector (1000 MT C)

Sector	*Auction*	*Grandfather*	*OBA/ Emissions*	*OBA/VA*
Electricity	11874	11859	11217	10448
Petroleum and coal products (refined)	7098	7042	3780	6679
Chemical industry	946	931	691	-496
Non-metallic minerals	927	926	855	265
Paper-pulp-print	161	159	166	-124
Iron and steel industry	573	586	526	410
Covered sectors	*21579*	*21504*	*17235*	*17183*
Other industry	-335	-389	1331	62
Primary energy	-1668	-1746	-1300	-1682
Services (excl. transport)	-1447	-1496	756	-1072
Transport	-6297	-6668	-1014	-6089
Final demand	3802	3226	901	2397
Uncovered sectors	*-5944*	*-7073*	*674*	*-6383*
Total	**15634**	**14431**	**17909**	**10799**

Table 8 shows that both forms of OBA are effective at limiting foreign emissions leakage from the covered sectors. However, while OBA/Emissions prevents more leakage from refineries and chemicals, it exacerbates leakage from the uncovered sectors, in large part due to fewer reductions at home, and generates the largest overall increase in net emissions outside the cap-and-trade program. OBA/VA, on the other hand, does not exacerbate leakage among the uncovered sectors, and since it actually diverts some production to regulated domestic industries, it results in the least leakage overall.

Welfare

Table 9 shows the welfare impacts on the U.S. and its trading partners. Although the changes are admittedly small (a fraction of a percent of the economy, are consistent with the range found by other climate models), the relative effects of the allocation scenarios are still illustrative. The world fares best when the U.S. uses auctioning with revenue recycling. While the U.S. experiences somewhat less of a welfare loss with value-added OBA, the rest of the world experiences the greatest loss in that scenario.

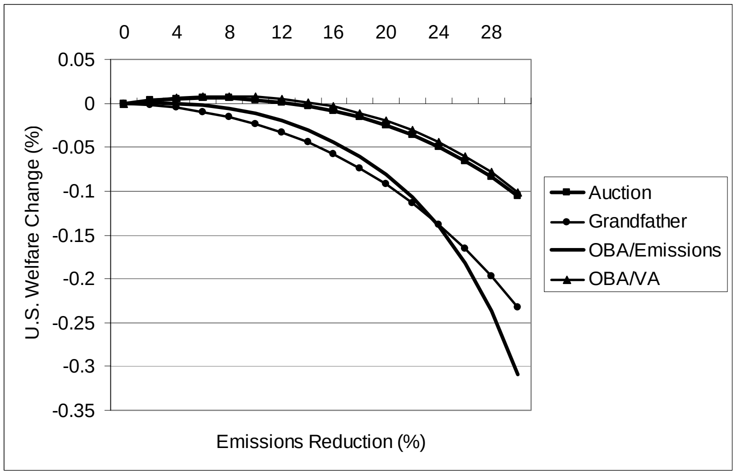
Table 9: Change in Welfare (Equivalent Variation, Millions of 2001 $)

Country	*Auction*	*Grandfather*	*OBA/ Emissions*	*OBA/VA*
United States	-1,508	-7,122	-5,546	-1,320
Excluding U.S.	305	507	-209	-3,038
World	-1,203	-6,615	-5,755	-4,358

However, this welfare change does not account for the differences in net emissions reductions among the policies. We also conducted policy scenarios targeting the same covered sectors but holding *global* emissions reductions constant. This change did not affect the relative ranking of Auction and OBA/VA; from a global perspective, OBA/VA does not offer the second-best optimal combination of emissions price and rebates.

However, from a U.S. perspective, OBA/VA dominates Auction, though only slightly, over a wide range of emissions reduction targets, as shown in Figure 2. OBA/Emissions, on the other hand, although it is initially preferred to grandfathering, ultimately becomes the most costly strategy when the reduction target is sufficiently stringent.

Figure 2: Sensitivity of U.S. Welfare Changes to Stringency of a Net Emissions Target



Conclusion

Simple economic models have produced a clear preference for using tradable emissions permits and auctioning the revenues to reduce labor taxes. However, this clear preference has generally not translated into the policy sphere, in which emissions permits are nearly always almost entirely given away, as in the U.S. SO2 trading program, the Clear Skies proposals, McCain Lieberman, and in the evolving EU carbon trading program, which imposes limits on auctioning. An exception is the Regional Greenhouse Gas Trading Initiative (RGGI), in which some states, particularly New York, have announced plans to auction. Furthermore, all of these programs limit their coverage to a select group of major emitters, leaving others uncovered by the regulation.

Contrary to the simple models, the actual policy situation is rarely simple. Competition through international trade, carbon leakage, and administrative issues likely hold more sway than tax interaction problems. In the case of such multiple problems, the allocation of emissions permits can have even more important effects. Specifically, when the cap-and-trade program is not applied economy-wide, there is a role for combining the regulation with output-based rebates targeted to the covered sectors. Auctioning with revenue recycling essentially gives these rebates economy-wide, which does not address the problem of emissions leakage. In this case, the costs of this domestic and foreign leakage can outweigh the benefits of a higher real wage and employment from the revenue recycling. Grandfathering, of course, has even more costly effects in terms of welfare, competitiveness, and leakage, though some agents will receive a windfall.

Output-based allocation may then emerge as a reasonable option to combine gratis allocation with incentives that mitigate impacts on consumers and trade. Still, we emphasize that the mechanism for determining the sector-level distributions has important consequences and tradeoffs. A rule based on historic emissions can actually exacerbate leakage, since the implicit subsidy for the heaviest polluters distorts relative energy prices, discouraging downstream consumers from conserving. A value-added rule, on the other hand, seems to do a better job of targeting the subsidy to prevent leakage. It also results in higher overall domestic welfare than with auctioned permits. However, it does promotes covered sectors to the detriment of uncovered ones, and it seems less efficient than auctioning from a global perspective.

Given that the overall gain of implementing a well-designed OBA program may be small, particularly relative to the risks of a poorly-designed one, further research is needed to assess this gratis distribution option. As a next step, we intend to solve for the optimal OBA design, that is, the optimal combination of auctioned permits and implicit subsidies to the covered sectors. We also plan to look at the sensitivity of the costs and benefits of OBA to the scope of program coverage; given that some climate policy proposals plan to address the electricity sector alone, while others would include both energy intensive sectors and transportation, this issue seems quite important. Another question is the effectiveness of OBA when certain foreign countries (like the EU) have an emissions cap on their covered sectors, which should limit potential leakage. These experiments will help elucidate the different roles of domestic and foreign emissions leakage in the tradeoffs between permit allocation regimes.

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[i] 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.