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# Is There a Rationale for Output-Based Rebating of Environmental Levies?

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## Abstract

Political pressure often exists for rebating environmental levies, particularly when incomplete regulatory coverage allegedly creates an “unlevel playing field” with other, unregulated firms or industries. This paper assesses the conditions under which rebating environmental levies is justified for the regulated sector, combining a theoretical approach with numerical simulations parameterized to reflect the Regional Greenhouse Gas Initiative. Rebates are undesired if one can instead tax the production of the unregulated sector. Otherwise, rebating is justified only when the goods of the competing sectors are close substitutes with similar emissions profiles. Policy constraints are costly in terms of welfare and environmental effectiveness.

**Key Words:** environmental tax, rebate, fiscal distortions, emissions permit allocation

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

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## Introduction

Environmental taxes, like many tax policies with a narrow focus, have long been tied to related expenditures. For example, France has used effluent fees to subsidize investments in abatement equipment, and the United States earmarked a “feedstock tax” on petroleum and chemical industries for financing Superfund cleanup operations.[1] Today, however, emissions taxes do more than finance environmental policies; more often they are the policies themselves. When price mechanisms, such as taxes or tradable permits, are levied on emissions to create incentives for environmental protection, the question arises of how to distribute the accompanying revenues, or rents.

Political pressure exists for environmental regulators to design self-contained, revenue-neutral policies.[2] The motives and methods for distributing the rents vary, however. Owners of sunk capital argue for grandfathered emissions permits or other lump-sum transfers as compensation for lost investments or forgone profits. This model was used in the 1990 Clean Air Act Amendments, which instituted an emissions trading program for sulfur dioxide ($SO_2$) in the United States: the permits were predominantly allocated according to the historical emissions of participants. However, grandfathering can transfer rents that far outweigh the actual costs of compliance.[3] Economists concerned about preexisting distortions in the economy then tend to argue for using the revenues to reduce income and other taxes. Another worry may be the

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[1] OECD (1993).

[2] Such revenue earmarking has been a focus in political economy, where earmarking can be shown to offer an enforcement mechanism for compromise among different interest groups (Wagner 1991). However, we abstract from the distributional issues behind these motivations.

[3] E.g., Bovenberg and Goulder (2001).

incomplete coverage of environmental regulation. Regulated sectors argue that to maintain a level, competitive playing field, the revenues should be used to subsidize their production. Environmental regulators might also worry that, without such subsidies, production would shift abroad to "pollution havens," countries with less stringent policies.

This paper focuses on the latter argument: the rationale that imperfect regulatory coverage creates for subsidizing regulated polluters. The issue bears some similarities to and some distinctions from the well-known literature on the interactions of environmental taxes with distortions created by labor income taxation (for a comprehensive collection, see Goulder 2002). The common problem is that some factor escapes taxation—in this case emissions, in the latter case leisure. As a result, the optimal tax is a second-best result with general equilibrium effects. In the tax-interaction models, the policy constraint is that needed revenue cannot be raised with lump-sum taxation; as a result, although the regulator is free to fully tax the externality, the optimal rate is typically lower than in the first-best setting, since the tax distortion increases the cost of the environmental policy. In this paper, lump-sum taxation is allowed, thus making a revenue constraint nonbinding and commodity taxation undesirable in the first-best case. Rather, the policy constraint is that one of the polluting sectors cannot be fully regulated. As a result, not only is the optimal emissions tax affected, but also the optimal commodity taxes—and we focus in particular on determining in which situations the optimal tax on the regulated commodity is significantly negative, implying that an output subsidy is desired.[4]

Some polluters may escape regulation for many reasons—technical, jurisdictional, political, or otherwise. Technical reasons can arise when firm-level monitoring of emissions is infeasible or prohibitively costly. For example, although continuous emissions monitoring for nitrogen oxides ($NO_x$) may be cost-effective for large electricity generators, it may not be for small ones, nor may it be feasible for nonpoint sources of pollution, like automobiles. Jurisdictional boundaries can mean that some polluters operate outside the regulator's reach, such as across state or national boundaries, or outside the particular controlled industry. For example, in some countries the department of the environment might be able to regulate stationary sources but not mobile ones, which are the domain of the transportation department; alternatively, the environmental agency might be authorized to regulate specific industries, like

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[4] This initial case is a necessary first step to develop intuition about regulatory constraints. In the conclusion we discuss how these two approaches might be combined to analyze the problem with both a regulatory and a revenue constraint, thus incorporating more complex tax interactions.

electricity generators, but a broad-based pollution tax on energy could require legislative approval. Furthermore, nondiscrimination requirements of trade agreements like the World Trade Organization or the U.S. Commerce Clause can prevent these jurisdictions from taxing imports of goods that escape pollution regulation.[5] Finally, sectors that are considered vulnerable or that are otherwise influential (steel or agriculture, for example) may be exempted for political reasons.

In the case of climate policy, there are many reasons why regulation of carbon dioxide ($CO_2$) might be uneven, both domestically and internationally. Some countries have committed to emissions caps under the Kyoto Protocol, while others have not; those that have committed, like the European Union, are implementing “downstream” systems that focus emissions permit trading on a few major sectors; other sectors are either left alone or face an assortment of policies, including indirect taxation of energy products. Energy-intensive industries then argue that without output subsidies, a policy of emissions prices alone will compromise their ability to compete with companies in nonparticipating countries. Participating countries worry that “carbon leakage” may limit the effectiveness of their efforts. Similarly, as some northeastern and neighboring mid-Atlantic states embark on the Regional Greenhouse Gas Initiative (RGGI) to curb $CO_2$ emissions from the electric power sector, they worry about leakage to nonparticipating states.[6]

In response, policymakers have proposed earmarking mechanisms aimed at alleviating or canceling the distortionary effect of pollution taxation vis-à-vis unregulated competitors. In particular, output-based rebating has emerged as a popular mechanism for integrating an offsetting subsidy into an environmental policy that raises production costs. Essentially, the revenues generated by the environmental policy are refunded back to the participants in proportion to their output, thus offering a production subsidy. Output-based rebating can take several forms: emissions taxes with rebates, output-allocated tradable emissions permits, and tradable performance standards, in which permits are allocated according to a pollution-intensity standard per unit of output. All these policies are similar forms of the same scheme: they each simultaneously impose a marginal cost on emissions and offer a subsidy to production.

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[5] Taxes can be levied on imports for pollution physically embodied in the goods, if domestic products are subject to such a tax. However, imports cannot be taxed based on emissions arising from the production process. See Fischer et al. (2003).

[6] Kruger and Pizer (2005).

Furthermore, the marginal value of that subsidy is not fixed but rather tied to the average value of inframarginal emissions to the affected industry.[7]

Some initial studies of rebating policies have been made, typically focusing on a specific type.[8] More attention has been paid to performance standards, for which several researchers have compared the efficiency effects to traditional tax or permit policies.[9] In the presence of preexisting tax distortions, these mechanisms can outperform a system of grandfathered emissions permits. Fischer and Fox (2004) consider different rules for output-based allocation and their effectiveness at combating carbon leakage, as well as tax distortions. However, the issue of *optimal* second-best subsidies has not received attention.

The purpose of this paper is to assess, on theoretical grounds and through numerical simulations, the desirability of such measures for correcting the distortion between the regulated and unregulated sectors. If an emissions tax can be imposed on one sector but not another, the next recourse is a system of commodity taxation on all goods. One might expect that a positive rate of taxation on the good produced by the unregulated sector, coupled with a negative tax (a rebate) in the regulated sector, would prove desirable. Analysis shows that only part of this intuition is true: it is (second-best) optimal to tax the unregulated sector, but not generally to rebate in the regulated sector.

If the unregulated sector is also untaxable, the rationale for a rebate in the regulated sector then appears stronger. However, rebating all the revenues is rarely ideal; the optimal rebate depends on the pollution intensity of the unregulated sector and the degree of substitutability between the goods. In fact, the desirability of the output rebate is not guaranteed; it is possible to show examples in which it is desirable that the regulated sector, though facing competition from an unregulated and nontaxable sector, be positively taxed. Only when the two sectors are close substitutes with similar emissions profiles does a 100 percent rebate approach the constrained optimum.

The next section presents the analytical model and the results for the optimal second-best tax rates. Then, numerical simulations, parameterized to reflect the RGGI case, are used to

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[7] Fischer (2001).

[8] Sterner and Isaksson (2006) focus on the Swedish $NO_x$ program; Jensen and Rasmussen (2000) look at permit trading with output-based allocation for $CO_2$.

[9] See Goulder et al. (1999), Parry and Williams (1999), Fullerton and Metcalf (2001), and Dissou (2005).

develop intuition about the effects of substitutability and damage costs on not only the optimal tax and rebate rates, but also the potential magnitude of the welfare losses and emissions, relative to optimal policy. The final section offers concluding thoughts.

## Model

The “minimal” representation of the economy necessary to cope with the issues at hand involves a model with two sectors (regulated and unregulated), two goods, and two factors of production (labor and emissions). Labor is considered the third good and (without loss of generality) taken as the numéraire and untaxed good (with its price set to unity). 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
$\tau_1$ = Tax on emissions in the regulated sector
$\tau_2$ = Tax on emissions in the unregulated sector
$T$ = Refund of tax revenues (lump-sum transfer)

### *Specifications*

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

$$U = U(C_1, C_2, 1-L). \tag{1}$$

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:[10]

$$D = D(E_1 + E_2)\,. \tag{2}$$

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

$$W = U - D = U(C_1, C_2, 1 - L) - D(E_1 + E_2). \tag{3}$$

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:

$$L_i = L_i(Q_i, E_i)\,. \tag{4}$$

## *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 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,

$$U(C_1, C_2, 1 - L) \tag{5}$$

subject to a budget constraint:

$$(\lambda) \quad p_1 C_1 + p_2 C_2 - wL - T = 0. \tag{6}$$

From the consumer problem, we obtain

$$(C_1)\ \frac{\partial U}{\partial C_1} = p_1\lambda; \qquad (C_2)\ \frac{\partial U}{\partial C_2} = p_2\lambda; \qquad (L)\ \frac{\partial U}{\partial L} = -\lambda w. \tag{7}$$

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[10] 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, as with a cap-and-trade policy, rather than given an emissions tax that equalizes marginal costs and benefits.

## Producer Problems

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

$$\pi_i = q_i Q_i - wL_i(Q_i, E_i) - \tau_i E_i , \tag{8}$$

from which we obtain

$$(Q_i)\ \ q_i = w\frac{\partial L_i}{\partial Q_i}; \qquad (E_i)\ \ -w\frac{\partial L_i}{\partial E_i} = \tau_i . \tag{9}$$

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.

## Market Equilibrium

In equilibrium, we have

$$C_1 = Q_1; \quad C_2 = Q_2; \quad L_1(Q_1, E_1) + L_2(Q_2, E_2) = L . \tag{10}$$

and $q_i = p_i - t_i$ .

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 on 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 $t_1, t_2, \tau_1,$ subject to the aforementioned constraints. The Appendix provides an alternative approach for solving this second-best optimization problem. However, the essence of the optimal tax problem can be seen by totally differentiating welfare:

$$dW = \frac{\partial U}{\partial C_1} dC_1 + \frac{\partial U}{\partial C_2} dC_2 - \frac{\partial U}{\partial l} dL - \frac{\partial D}{\partial E}\left(dE_1 + dE_2\right). \qquad (11)$$

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

$$dW = p_1 \lambda dC_1 + p_2 \lambda dC_2 - \lambda w dL - D'\left(dE_1 + dE_2\right). \qquad (12)$$

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

$$\frac{1}{\lambda}\frac{dW}{dt_2} = t_1 \frac{dC_1}{dt_2} + t_2 \underbrace{\frac{dC_2}{dt_2}}_{-} + \left(\tau_1 - \frac{D'}{\lambda}\right)\frac{dE_1}{dt_2} + \left(\tau_2 - \frac{D'}{\lambda}\right)\underbrace{\frac{dE_2}{dt_2}}_{-}; \qquad (13)$$

$$\frac{1}{\lambda}\frac{dW}{dt_1} = t_1 \underbrace{\frac{dC_1}{dt_1}}_{-} + t_2 \frac{dC_2}{dt_1} + \left(\tau_1 - \frac{D'}{\lambda}\right)\underbrace{\frac{dE_1}{dt_1}}_{-} + \left(\tau_2 - \frac{D'}{\lambda}\right)\frac{dE_2}{dt_1}; \qquad (14)$$

$$\frac{1}{\lambda}\frac{dW}{d\tau_1} = t_1 \underbrace{\frac{dC_1}{d\tau_1}}_{-} + t_2 \frac{dC_2}{d\tau_1} + \left(\tau_1 - \frac{D'}{\lambda}\right)\underbrace{\frac{dE_1}{d\tau_1}}_{-} + \left(\tau_2 - \frac{D'}{\lambda}\right)\frac{dE_2}{d\tau_1}. \qquad (15)$$

**First Best**

From these equations, it is easy to see that if $\tau_1 = \tau_2 = D'/\lambda$, then $t_1 = t_2 = 0$: evaluating $dW/dt_i$ at that point, marginal welfare is declining with any deviation in $t_i$ from 0, since $t_i$ and $dC_i/dt_i$ take opposite signs. In other words, at the welfare optimum, when the emissions externality is fully internalized with Pigouvian taxes, no output taxes or subsidies are needed.

**Unregulated Sector 2**

However, when $\tau_2 = 0$, the second-best optimum implies

$$\tau_1 = \frac{D'}{\lambda}; \quad t_1 = 0; \quad t_2 = \tau_1 \frac{dE_2}{dC_2}. \qquad (16)$$

These results are also simple to interpret:

- emissions in sector 1 are taxed according to marginal damages;
- there is neither tax nor rebate for commodity 1; and
- commodity 2 is taxed according to the marginal damages of the associated emissions.

The expression for $t_2$ reveals that the tax rate on sector 2 equals the pollution tax applied in sector 1 multiplied by the marginal propensity to emit. Thus, if emissions from the exempt sector are insignificant, the optimal commodity tax will be negligible. More generally, the optimal commodity tax reflects the average tax payments that would accrue from a pollution tax. However, the rate and level of emitted pollution are higher than in the first-best case because the incentive effect is not at work. As a result, the optimized unregulated equilibrium exhibits a welfare loss relative to the first-best, which can be measured and will be calculated in numerical simulations.

**Unregulated, Untaxed Sector 2**

Now suppose sector 2 cannot be taxed at all—neither its emissions nor its output. A unilateral tax on sector 1's emissions raises the relative price of good 1. To alleviate the distortion to competition, it may be desirable to subsidize sector 1—that is, impose a negative commodity tax. Such a result is not assured, however.

Simplifying the equations for the welfare changes, we have

$$\frac{1}{\lambda}\frac{dW}{dt_1} = t_1 \underbrace{\frac{dC_1}{dt_1}}_{-} + \left(\tau_1 - \frac{D'}{\lambda}\right)\underbrace{\frac{dE_1}{dt_1}}_{-} - \frac{D'}{\lambda}\frac{dE_2}{dt_1}; \tag{17}$$

$$\frac{1}{\lambda}\frac{dW}{d\tau_1} = t_1 \underbrace{\frac{dC_1}{d\tau_1}}_{-} + \left(\tau_1 - \frac{D'}{\lambda}\right)\underbrace{\frac{dE_1}{d\tau_1}}_{-} - \frac{D'}{\lambda}\frac{dE_2}{d\tau_1}. \tag{18}$$

In this case, the second-best policy combination implies

$$\tau_1 = \frac{D'}{\lambda}; \quad t_1 = \tau_1 \frac{dE_2}{dC_1}. \tag{19}$$

The emissions tax in sector 1 affects $C_1$ and $E_2$ in the same way as an output tax, by increasing marginal costs for that sector. Thus, there is no reason for the emissions tax to deviate from the Pigouvian level, since the output tax can be used to influence those variables. Still, the optimal emissions tax in this case will differ from the less constrained cases, since equilibrium marginal damages and the marginal utility of consumption will differ.

The optimal tax on the regulated sector reflects the marginal value of the change in emissions in sector 2 that it induces. If the goods are substitutes, then $dE_2 / dC_1 < 0$, and an output subsidy is justified. The strength of that subsidy depends on both the strength of that substitution effect $dC_2 / dC_1$ and the marginal emissions in the other sector $dE_2 / dC_2$.

Under what circumstances might 100 percent rebating be justified, as with a performance standard or output-based rebating? This policy implies that the total subsidy equals the total revenue from the emissions tax: $t_1 C_1 = \tau_1 E_1$. Substituting the optimal tax values and rearranging, we get

$$\frac{dE_2}{dC_1} = \frac{E_1}{C_1}. \tag{20}$$

Thus 100 percent rebating is optimal if the emissions in sector 2 displaced by the additional output in 1 equal the average emissions rate in sector 1. Logically, this condition is most likely to hold when the two goods are close substitutes and have similar emissions profiles. In other words, output-based rebating can be justified when parts of the same competitive sector cannot be regulated or taxed. However, output-based rebating is suboptimal when the two sectors are not direct competitors, or the competing sector has relatively low emissions. For example, if the regulated sector is electricity generation, significant rebating would not be justified because the transportation sector is exempt, or because renewable energy is exempt. On the other hand, if industrial boilers or out-of-state coal-fired plants in the same airshed and on the same grid are exempt from air emissions regulation, rebating may be a reasonable response.

More generally,

$$\begin{aligned} t_1 &= \frac{D'}{\lambda}\frac{dE_2}{dC_1} + \left(\frac{D'}{\lambda} - \tau_1\right)\frac{dE_1}{dC_1} \\ \tau_1 &= \frac{D'}{\lambda} + \left(\frac{D'}{\lambda}\frac{dE_2}{dC_1} - t_1\right)\frac{dC_1}{dE_1} \end{aligned} \tag{21}$$

## Numerical Model

The preceding analytical results indicate the optimal tax response to regulatory constraints, but they cannot reveal the magnitude of the welfare loss associated with those constraints or the optimal tax levels that arise from these equilibria. To develop intuition about those impacts and their sensitivity to important parameters like marginal damages and substitutability, we employ a simple numerical model. (A complete specification of the second-best optimization problem, which is the analytical foundation for the numerical model, is laid out in the Appendix.) We then parameterize it to reflect the U.S. economy and electricity sector. We consider the rationale for optimal rebating when some states regulate carbon emissions while others do not, as with the Regional Greenhouse Gas Initiative. This program, in which northeastern and mid-Atlantic states are joining together to develop a regional cap-and-trade program for $CO_2$, represents a good case study for the value of policy options (and the costs of constraints) in the face of incomplete participation. In this case, the emissions price sets an equivalent pollution tax, while the allocation mechanism allows for the possibility of a rebate, in the form of updating based on output.[11]

## Policy Scenarios

Table 1 presents the policy scenarios evaluated with the parameterized model. In addition to the first-best policy and the two second-best policies analyzed in the previous section, we consider the case of a mandatory 100 percent rebate of the pollution tax in sector 1. Even though we have demonstrated it is not usually optimal, it is frequently advocated, so an important question is the extent of efficiency loss with this strategy compared with other policies. Finally, we also consider the effectiveness of taxing only pollution in sector 1, with no other taxes or rebates.

We compare the effects of these different policy constraints on welfare, emissions, and the emissions tax rate. We also explore the relationship between substitutability among the goods and the optimal (constrained) policy parameters.

## Model Specifications

### Utility

Though it is not the most general specification, a convenient one for the subsequent numerical analysis is the two-level nested CES utility function. For three goods, $X_1$, $X_2$, and $X_3$,

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[11] The majority of allowance allocation is up to the discretion of the states, and the updating option is one of several allocation mechanisms being considered (Burtraw et al. 2005).

its formulation is

$$U = \left[ uZ^{-\mu} + (1-u) X_3^{-\mu} \right]^{-\frac{1}{\mu}}, \text{ with } Z = \left[ vX_1^{-\nu} + (1-v) X_2^{-\nu} \right]^{-\frac{1}{\nu}}. \qquad (22)$$

This function is homogeneous of degree one and separable; although it is not the most general specification, it allows us to capture various possible relations of substitutability and complementarity. The elasticities of substitution are $s_1 = \frac{1}{1+\mu}$ in the global function and $s_2 = \frac{1}{1+\nu}$ in the nest. Note that in this simple, general equilibrium model, substitutability is determined relative to the third good.[12]

### Damages

We assume linear damages: $D = (E_1 + E_2)\delta$. Although marginal damage costs are constant, the value of marginal damages depends on the marginal utility of consumption as well.

### Production

By definition, the unregulated sector receives no direct price signal for emitting pollution; consequently, it sets its emissions at a level such that the marginal productivity is always zero. Logically, emissions must be finite, whatever the expected production, and we have to represent this property in the specification of the production function. More precisely, the production function must be such that when the pollution price is zero, labor and emissions become simple functions of the level of production. The intuition is that, when the marginal productivity of emissions is always zero, any level of output can be achieved only with a unique amount of labor and emissions: $E = \psi(Q)$, and $L = \varphi(Q)$.

A fairly general specification for a sector production function with the necessary properties is (leaving off the sector index subscripts for the moment) $L = \alpha Q + g[Q/E]$, in which $\alpha$ is a constant and *g* is a monotonic increasing function of the average product of emissions (the inverse of emissions intensity). Let $m = E/Q$ represent the emissions rate, so *x* =

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[12] In a full-scale trade model (GTAP, for example), the substitution effect $dC_2 / dC_1$ would depend not only on the elasticity of substitution in the nest, the preference for domestic or imported goods (*v* in our model), and the preferences and elasticities of substitution in the utility function, but also on multisector general equilibrium effects, including cross-sector complementarities that arise through production input relationships.

1/*m*. Let $g(x)=\beta\left(\bar{m}x^{n}-\frac{n}{n-1}x^{n-1}\right)+c$, where $\bar{m}$ is the baseline emissions rate, and $\beta$ and *c* are constants. An important condition is that the marginal productivity of pollution equal zero at finite emissions; for this function, the solution of $g'(x)=nx^{n-1}-nx^{n-2}=0$ implies $x=1/\bar{m}$. The parameter *c* represents a calibration adjustment to avoid positive profits in the baseline scenario ($c=\beta\bar{m}^{1-n}/(1-n)$); in other cases, profits are assumed to be transferred to consumers as shareholders in lump-sum fashion. Then, in the case of no emissions tax, the factor functions for sector 2 reduce to

$$E_2=\bar{m}Q_2; \qquad L_2=\phi Q_2. \tag{23}$$

The corresponding marginal labor requirement (the inverse of the marginal product of labor) is

$$\frac{\partial L}{\partial Q}=\alpha+n\beta\left[\frac{\bar{m}-m}{m^{n}Q}\right]. \tag{24}$$

The parameter $\alpha$ represents the (constant) direct marginal production costs (in terms of labor units needed), while $\beta$ shifts those marginal costs upward, to the extent that the emissions rate falls below the zero-marginal-product rate of emissions. The marginal labor requirement arising from additional emissions is

$$\frac{\partial L}{\partial E}=n\beta\left[\frac{m-\bar{m}}{m^{n+1}Q}\right], \tag{25}$$

which is negative for any emissions rate lower than the baseline.

For most scenarios the value of $\beta_2$ is not very important, since in the absence of an emissions charge in that sector, the term functions like a residual in the production function and does not affect marginal labor costs. It does, however, matter in terms of relative welfare losses. Raising $\beta_2$ raises abatement costs in sector 2, meaning less would be done in the presence of a direct emissions tax. Therefore, the relative welfare loss from policy restrictions is decreasing in $\beta_2$.

## *Calibration*

We calibrate this model to represent two electricity sectors and the rest of the economy. We postulate scenarios in which some states decide to go ahead with mandatory carbon controls while others do not. The participating states are assumed to be those participating in RGGI, its observer states, and California.[13] In our simulation, $X_1$ is electricity production by those states, $X_2$ is production in nonparticipating states, and $X_3$ is everything else. To focus on the roles of the first two sectors, in line with the theoretical model, we ignore the emissions of the third sector and assume it is clean.

As is the case in general equilibrium modeling, the first step is calibration to a reference scenario, which is here the market equilibrium without pollution damages ($\delta = 0$). In Table 2, the initial values for output are represented in dollar values, implying all initial prices are normalized to 1. Output values are for 2001 and originate from GTAP,[14] and they are apportioned among RGGI and non-RGGI states according to the Energy Information Administration (EIA 2004a), which also provided emissions rate information.[15]

As for the main parameters of the production functions, we use $\alpha_1 = \alpha_2 = 1$ and calibrate the function $g(.)$ with two studies of carbon constraints on the U.S. electricity sector using the National Energy Modeling System (NEMS), EIA (1998) and EIA (2004b). The former study of the Kyoto Protocol evaluated six scenarios, giving six pairs of carbon prices and emissions rates for the electricity sector. From these results, we estimated that $n = 3$ represented the best fit for our function. We then used the more recent study of the Climate Stewardship Act, even though it evaluated only two scenarios, to calculate the $\beta$ parameters, using the average for the scenarios.[16] Note that these estimates are sensitive to the initial values of output and emissions, so in our sensitivity analysis, in which we consider the effects of different relative emissions rates, the $\beta$ parameters also change. We note those central and alternative assumptions in Table 3.

Other key parameters for optimal tax values are the elasticities of substitution between the goods, as illustrated in Table 4. In the central scenario, we assume that the elasticity within the nest (i.e., between electricity in RGGI and non-RGGI states) is a relatively elastic 2.0, while

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[13] Participating states are Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont; Maryland will join them in 2007. Observing jurisdictions are the District of Columbia, Massachusetts, Pennsylvania, and Rhode Island, plus the eastern Canadian provinces, New Brunswick, and California (http://www.rggi.org/states.htm).

[14] https://www.gtap.agecon.purdue.edu/databases/v6/default.asp (accessed 2/27/06).

[15] http://www.eia.doe.gov/cneaf/electricity/st_profiles/profiles.pdf. Certain corrections in this version had to be made from the individual state reports in EIA (2004a).

[16] From the first-order condition, we get $\beta = \tau m^4 Q / 3/(m - \overline{m})$. These estimates are also largely consistent with those using the Kyoto study.

electricity is a relative complement to the rest of the economy, with an inelastic substitution elasticity of 0.25. We also conduct sensitivity analysis for $s_2$, considering a less elastic case of 0.75, which might be the case with more interregional transmission constraints, for example, and a more elastic case of 5.0, which could reflect more competitive interstate markets.

Given these assumptions, *u* and *v* are then calibrated to replicate the baseline (no-policy) scenario.

## *Results*

We present the results, generally expressed in relation to optimal policy, in the following sets of figures. They show the magnitude of tax and welfare differences as the externality cost $\delta$ ("Damage Rate") varies from $0 to $50/MtC. They clearly demonstrate the importance of the substitutability between the two commodities and of the relative emissions intensities for optimal tax and rebate policies.[17]

### Rebate Rate

The rebate rate in sector 1 is the ratio of subsidies to pollution tax revenues from that sector (i.e., $-t_1 C_1 / \tau E_1$). We see that in the central scenario, the optimal rebate rate exceeds 140 percent, in large part because the unregulated sector is more emissions intensive. When the baseline emissions rates are assumed to be equal, the optimal rebate falls well under 100 percent, and when the emissions rates are reversed, making the regulated sector the greater polluter, the optimal rebate rate falls to the 50–60 percent range. Figure 1 depicts the optimal rebate rates as a function of the marginal damages from carbon emissions for the three emissions rate scenarios.

However, the elasticity of substitution also explains the optimal rebate rate. When the two sectors are not as strong substitutes, the rebate rate falls, as depicted in Figure 2.

More generally, the less substitutable are the two sectors between each other (relative to the rest of the economy), the less efficient is a price differential for inducing pollution abatement, because it does not change their relative demand as much.

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[17] The underlying assumptions regarding the use of emissions in each production function are also important, as noted regarding the calibration of $\beta$.

### Emissions Tax Rate

Regarding the actual level of taxation, the differences are very small in these simulations because of the overwhelming size of the third sector and the assumption of linear damages, which limit variability in the value of marginal damages. We note that, relative to the first-best case, the constrained optimal emissions tax rate is slightly higher when the unregulated sector can be taxed and lower when it cannot. The reason is that the commodity tax helps maintain the effectiveness of the emissions tax, while the rebate encourages electricity consumption and limits the ability of the emissions tax to encourage abatement. Similarly, consumption of the third good is slightly higher with the tax on sector 2 and lower in the rebate scenarios, since electricity prices fall.

### Emissions

We see these effects reflected in the impacts of the policy constraints on emissions outcomes, as portrayed in Figure 3. With each additional policy restriction, total emissions rise. Note that the opportunities for sector 2 (the nonparticipating states) to cost-effectively reduce emissions determine the size of the gap between emissions in the first-best case and the unregulated sector 2 case. However, the difference between the other scenarios depends not on these opportunities but rather on each policy's ability to crowd out output from the unregulated sector.

### Welfare

The ultimate question is how the constraints, given these optimal responses to them, affect welfare. Figure 4 depicts the welfare gains from each kind of policy as a share of total gains from first-best regulation. Clearly, policy constraints are very costly in terms of welfare, and the welfare costs increase with the stringency of the restrictions. The welfare costs are also quite sensitive to the degree of the emissions leakage problem.

In the central scenario, the unregulated electricity sector has a higher emissions rate than the regulated one. We see in this example that with the single restriction of no pollution regulation for one sector, even with the option of commodity taxation, two-thirds or more of the welfare gains from environmental policy are forgone. Removing the option to tax the unregulated sector directly, even allowing for rebating, means that only 10 to 15 percent of the potential gains from environmental policy can be achieved. The additional constraint of mandatory, rather than optimal, rebating imposes a relatively small additional loss. Finally, with no rebate available, no gains can be captured at all; an emissions tax on sector 1 actually reduces welfare, since it causes emissions to rise in the unregulated sector 2 more than it reduces emissions in sector 1. On the other hand, when the baseline emissions rates are reversed, meaning the regulated sector comprises the more intense polluters, more of the potential welfare gains can be captured, though still less than half, even with the commodity tax option. Optimal rebating then offers about a third of the potential gains, and no rebating achieves 20 to 25 percent.

Implicitly, the welfare costs are increasing with not only the emissions of the unregulated sector, but also the ease with which those emissions could be abated in the first-best scenario. Although substitution elasticities certainly play a role, they seem to have much less impact on the relative welfare effects of the constrained policies than do the relative baseline emissions rates. These results signal the importance of allocation program design for the success of the RGGI, as well as the limitations of such a program while its membership remains incomplete.

## Conclusion

We have considered the arguments for allocating environmental revenues in the form of output subsidies to affected industries. The desirability of such a policy depends on the circumstances of the constraint on policymaking, the emissions intensity of the exempt production, and whether the goods of the regulated industry are substitutes for or complements of those of the unregulated industry.

As usual, the first-best policy is always to have a full set of policy tools. Then the emissions of each industry are taxed directly, and the revenues are refunded in a nondistorting manner to consumers. However, if for some reason the emissions of one of the polluting sectors cannot be regulated directly, the next-best response is to tax those emissions indirectly. A tax should be levied on the output of the unregulated sector, reflecting the extent to which emissions are incorporated in its production. Meanwhile, a direct tax on the regulated sector’s emissions remains in place, and the revenues are again refunded in lump sum; no rebate is justified.

If taxing the unregulated sector’s output is not possible either, then an output-based rebate to the regulated sector is justified, but only to the extent that (i) the goods are close substitutes and (ii) the unregulated sector is polluting.

Requiring that the rebate rate equal 100 percent for the regulated sector represents an additional policy constraint and thus reduces welfare compared with the previous scenario. Obviously, such a requirement is least costly when the optimal rebate rate is close to 1, as when both the goods and their emissions profiles are similar. In a complements situation, a mandatory full rebate is worse than no rebate at all. In any case, the loss in terms of flexibility for setting the rebate can be more than compensated for if a tax can also be levied on the output of the unregulated sector.

Policy constraints can be quite costly, and a general equilibrium framework is important for understanding the potential magnitude of those costs. The effectiveness of the remaining policy tools depends critically on the elasticities of substitution and the relative emissions profiles. This means that the rationale for combining an emissions tax with an output rebate must be evaluated on a case-by-case basis. In some cases, a rebate may not be justified. For example, the fact that the transportation industry escapes $CO_2$ taxation would not justify a rebate for the electricity sector, since the sectors do not really compete with each other; in fact, if fuel inputs must be transported by the unregulated sector, a negative rebate could in theory be justified. Nor is close substitutability sufficient: if the competing unregulated producers used carbon-free technologies like nuclear, wind, solar, or biofuel, then output substitution can be an important means of reducing overall compliance costs for a $CO_2$ regulation.

In other cases, a rebate is highly justified. For example, we parameterized the model to reflect a scenario in which some states regulate the $CO_2$ emissions of their electricity generators, while others do not. When the emissions rates are higher in the states without the regulation, the rebate enables the regulation to have some positive effect, although it remains difficult for any unilateral policy to capture a large share of the potential gains from nationwide $CO_2$ regulation. The message for the RGGI is cautionary: careful design of the permit allocation program will be needed to generate true emissions reductions in the short run, and the long-run focus must be on expanding the program nationwide to achieve significant results.

Since the special situation of similar, close competitors' being unregulated often arises due to jurisdictional limitations, this case deserves more extensive analysis. The model here would represent the problem of a global planner; it does not differentiate between welfare in different jurisdictions. Once this distinction is made, more interesting questions emerge regarding regulatory competition, transboundary pollution, and strategic trade.

An important distinction between the tax interaction models and this incomplete regulation model involves the formulation of the three goods. The double-dividend literature typically has two taxable commodities, one dirty and one clean, and leisure, which is clean and untaxable. In our model, leisure is clean and untaxed, but both the taxable commodities are dirty; the key constraint is that the emissions of one are untaxable. Absent any direct emissions tax, the optimal labor tax would tend to be less distorting, since some shifting away from the dirty commodities is desired. However, in switching from that regime to an emissions tax on one of the commodities, the optimal revenue recycling will not typically be an even reduction of the labor tax, but rather, it will be differentiated by the commodities (with less going to the untaxed polluter). Additional restrictions, like an undifferentiated commodity tax, will then affect the optimal level of the emissions tax. However, a richer treatment of tax interactions would involve adding a fourth good to the model—a clean, taxable commodity. Then both the disparity in treatment among commodities and the labor-leisure tradeoff could be addressed.

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## Appendix

### *Second-Best Optimization*

When sector 2 is unregulated, we have seen that its emissions adjust so that the marginal product is always zero. A planner then cannot influence emissions directly but only indirectly, through the output choice, of which emissions are then a straightforward function. When sector 2 cannot be taxed, the planner can no longer affect the output choice directly, either. Output in sector 2 then becomes a function of the general equilibrium of the system.

Taking into account direct constraints—or indirect, such as budget constraints—on the price system requires resorting to the classic second-best apparatus. The critical variables are now not quantities but prices: the production prices, the pollution tax, the consumption prices (and then implicitly the commodity taxes), and the household’s income *R*. Labor is chosen as the numéraire and the untaxed good (without loss of generality), with its price is set to 1. The second-best problem can now be written in the following form.

The planner maximizes

$$U(p_1, p_2, R) - \delta\left[E_1(q_1, w, \tau) + E_2(q_2, w)\right] \tag{a1}$$

subject to the constraints

$$\begin{aligned} &(\pi_1) \quad C_1(p_1, p_2, R) - Q_1(q_1, w, \tau) = 0 \\ &(\pi_2) \quad C_2(p_1, p_2, R) - Q_2(q_2, w) = 0 \\ &(\omega) \quad L_1(q_1, w, \tau) + L_2(q_2, w) - L(p_1, p_2, R) = 0. \end{aligned} \tag{a2}$$

The optimality conditions are

$$\begin{aligned} &(p_1)\ \frac{\partial U}{\partial p_1} = \pi_1 \frac{\partial C_1}{\partial p_1} + \pi_2 \frac{\partial C_2}{\partial p_1} - \omega \frac{\partial L}{\partial p_1} && (q_1)\ -\delta \frac{\partial E_1}{\partial q_1} = -\pi_1 \frac{\partial Q_1}{\partial q_1} + \omega \frac{\partial L_1}{\partial q_1} \\ &(p_2)\ \frac{\partial U}{\partial p_2} = \pi_1 \frac{\partial C_1}{\partial p_2} + \pi_2 \frac{\partial C_2}{\partial p_2} - \omega \frac{\partial L}{\partial p_2} && (q_2)\ -\delta \frac{\partial E_2}{\partial q_2} = -\pi_2 \frac{\partial Q_2}{\partial q_2} + \omega \frac{\partial L_2}{\partial q_2} \\ &(R)\ \frac{\partial U}{\partial R} = \pi_1 \frac{\partial C_1}{\partial R} + \pi_2 \frac{\partial C_2}{\partial R} - \omega \frac{\partial L}{\partial R} && (\tau)\ -\delta \frac{\partial E_1}{\partial \tau} = -\pi_1 \frac{\partial Q_1}{\partial \tau} + \omega \frac{\partial L_1}{\partial \tau} \end{aligned} \tag{a3}$$

The global system comprises nine relations and nine variables, and although it is not guaranteed in all circumstances, generally there is a unique solution. The solution can be obtained by transforming the system of optimality conditions and replacing uncompensated derivatives of demand with compensated derivatives (the sign of which is known, under the assumption that the utility function is quasi-convex[18]).

Effectively, adding equation $(p_1)$ to equation $(R)$, multiplied by $C_1$ (and similarly for good 2) yields

$$\boxed{\begin{array}{l} 0 = \pi_1 s_{11} + \pi_2 s_{12} - \omega s_{1L} \\ 0 = \pi_1 s_{12} + \pi_2 s_{22} - \omega s_{2L} \\ \lambda = \pi_1 v_1 + \pi_2 v_2 - \omega v_L \end{array}}, \qquad \text{(a4)}$$

where $\lambda = \frac{\partial U}{\partial R}$ is the marginal utility of income, $s_{ij} = \frac{\partial C_i}{\partial p_j} + C_j \frac{\partial C_i}{\partial R}$ is the compensated derivative of demand in commodity *i*, and $v_i = \frac{\partial C_i}{\partial R}$ is the derivative of demand in commodity *i* with respect to income.

The above system is identically verified for $\pi_1 = p_1; \pi_2 = p_2; \omega = w$. Assuming uniqueness of the solution then shows that the social values of goods are equal to the consumption prices. The same reasoning applied to sector 1 shows that the production prices are equal to the social values of goods, and that $p_1 = q_1$, meaning that no commodity taxation is warranted in sector 1. As for sector 2, the dual relation is as presented before. Commodity 2 is optimally taxed at a rate equal to the pollution tax (as applying to sector 1) multiplied by the marginal associated emissions.

Suppose now that unregulated sector 2 cannot be taxed at all. Imposing a zero tax in sector 2 (i.e., the condition that $q_2 = p_2$) modifies the optimization problem and the optimality conditions in that $p_2$ replaces $q_2$ in the target function and in the constraints ($\pi_2$) and ($\omega$). Correspondingly, optimality conditions ($p_2$) and ($q_2$) are gathered into a single constraint:

$$(p_2) \quad \frac{\partial U}{\partial p_2} - \delta \frac{\partial E_2}{\partial p_2} = \pi_1 \frac{\partial C_1}{\partial p_2} + \pi_2 \frac{\partial C_2}{\partial p_2} - \omega \frac{\partial L}{\partial p_2} - \pi_2 \frac{\partial Q_2}{\partial p_2} + \omega \frac{\partial L_2}{\partial p_2}. \qquad \text{(a5)}$$

The global system (primal and dual) consists now of eight relations and eight variables, reflecting the limitation to two of the policy instruments (the pollution tax and the commodity tax, both of which apply to sector 1). The above formula clearly shows that the social values of goods no longer coincide with the consumption prices. As a consequence, the optimal tax on

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[18] More precisely, the matrix of compensated demand derivatives is negative semidefinite.

commodity 1 is no longer equal to zero. The numerical simulations help develop a more thorough understanding of the general equilibrium workings of the system.

## Tables

### Table 1. Comparison of Scenarios

| | *Pollution tax in sector 1* | *Pollution tax in sector 2* | *Commodity tax in sector 1* | *Commodity tax in sector 2* |
|---|---|---|---|---|
| First-best | Yes | Yes | Yes (= 0) | Yes (.= 0) |
| Unregulated sector 2 | Yes | No | Yes | Yes |
| Untaxed (and unregulated) sector 2 | Yes | No | Yes | No |
| 100% rebating in sector 1 (performance standard) | Yes | No | 100% rebate | No |
| No rebate | Yes | No | No | No |

### Table 2. Baseline Values

| | *RGGI electricity* | *Non-RGGI electricity* | *Rest of economy* |
|---|---|---|---|
| Q, L (2001$ trillion) | 0.05403 | 0.20482 | 18.10661 |
| $\bar{m}$ (kg C/$) | 1.58 | 2.63 | 0 |

### Table 3. Alternative Assumptions

| | *Central scenario* | *Equal emissions rates* | *Reversed emissions rates* |
|---|---|---|---|
| $\bar{m}_1$ (kg C/$) | 1.58 | 2.41 | 2.63 |
| $\bar{m}_2$ (kg C/$) | 2.63 | 2.41 | 1.58 |
| $\beta_1$ | 0.02 | 0.06 | 0.08 |
| $\beta_2$ | 0.30 | 0.23 | 0.07 |

### Table 4. Alternative Elasticity Assumptions

| | *Central scenario* | *Stronger substitutes* | *Weaker substitutes* |
|---|---|---|---|
| $s_2$ | 2.00 | 5.00 | 0.75 |
| $s_1$ | 0.25 | 0.25 | 0.25 |

## Figures

Figure 1. Optimal Rebate Rate and Relative Emissions Intensity

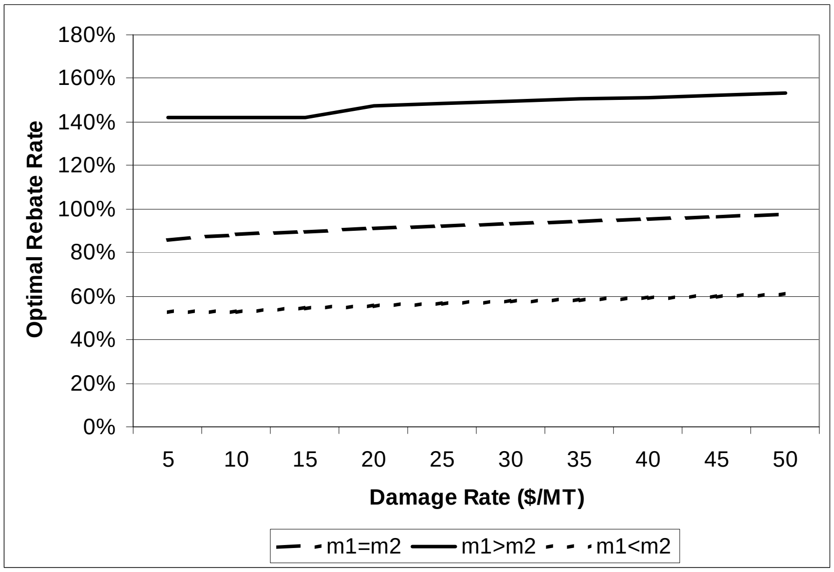


Figure 2. Optimal Rebate Rate and Substitutability

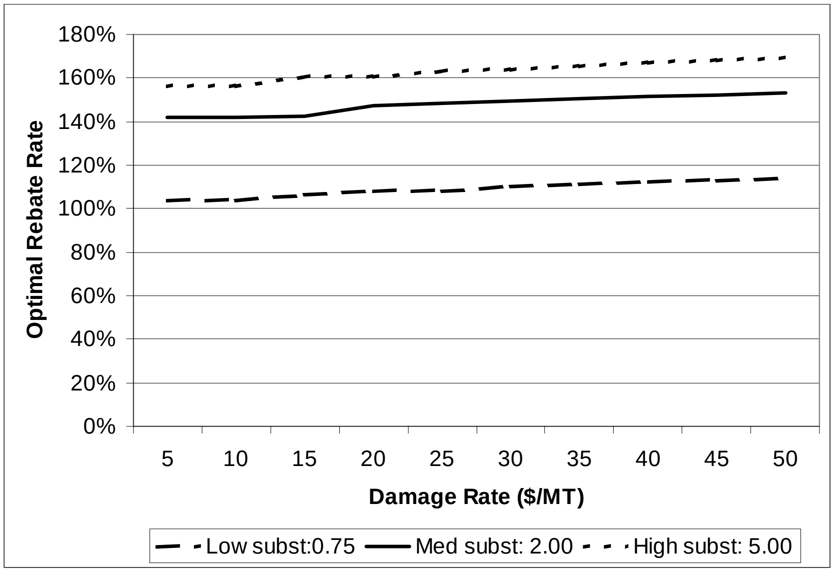
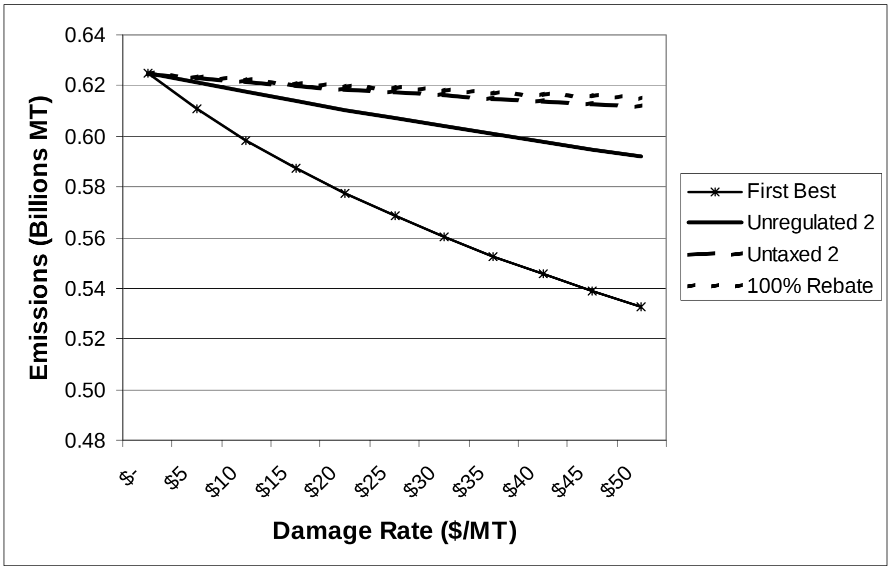
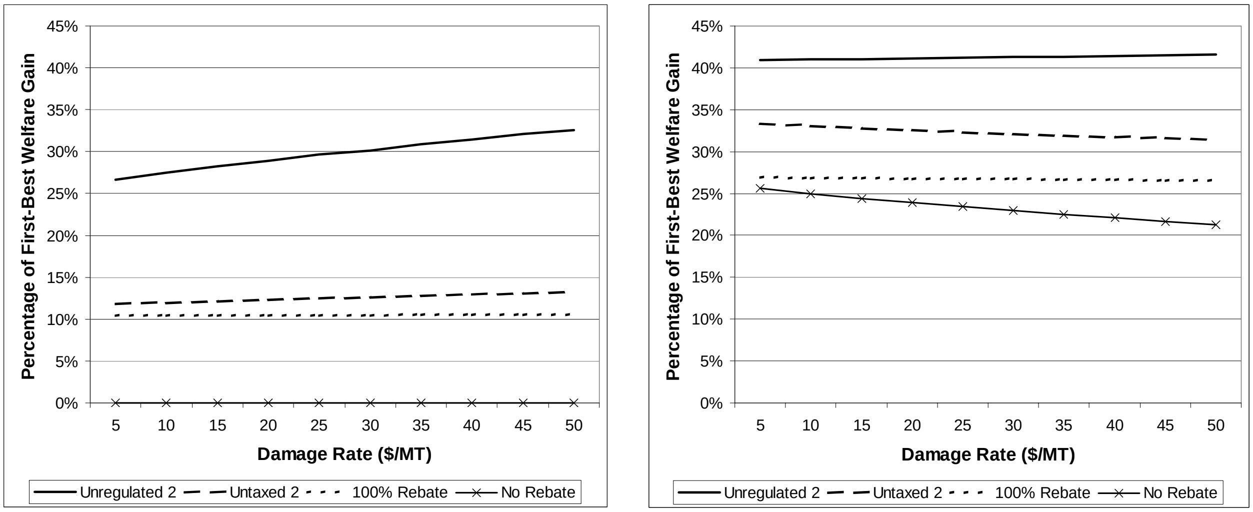


Figure 3. Emissions by Policy



# Figure 4. Welfare Gain from Constrained Policies as a Share of Optimal Gains



**Central Scenario ( $m_1 < m_2$ )**

**Reverse Emissions Intensities ( $m_1 > m_2$ )**