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Costs of alternative environmental policy instruments in the presence of industry compensation requirements ☆

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Abstract

This paper explores how the costs of meeting given aggregate targets for pollution emissions change with the imposition of the requirement that key pollution-related industries be compensated for potential losses of profit from the pollution regulation. We apply a numerically solved general equilibrium model to compare the incidence and costs of emissions taxes, fuel (intermediate input) taxes, performance standards and mandated technologies in the absence and presence of this compensation requirement. Compensation is provided either through industry tax credits or industry-specific cuts in capital tax rates.

We analyze the added costs from the compensation requirement in terms of (1) an increase in "intrinsic abatement cost," reflecting a lowered efficiency of pollution abatement, and (2) a "lump-sum compensation cost" that captures the efficiency costs of financing the compensation. The compensation requirement affects these components differently, depending on the policy instrument involved and the required extent of pollution abatement. As a result, it can change the cost rankings of the different instruments.

In particular, when compensation is provided through lump-sum tax credits, the lump-sum compensation cost is higher under the emissions tax than under the command-and-control policies (performance standards and mandated technologies) — a reflection of the higher compensation requirements under the emissions tax. When the required pollution reduction is modest, imposing the compensation requirement causes the emissions tax to lose its status as the least costly instrument and to become more costly than command-and-control policies. In contrast, when required abatement is extensive, the emissions tax again becomes the most cost-effective instrument because of its advantages in terms of lower intrinsic abatement cost.
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1. Introduction

A critical environmental policy decision is the choice of policy instrument to achieve given aggregate targets for pollution emissions or concentrations. The policy maker's toolkit includes emissions taxes, fuel taxes, performance

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standards, tradable emissions allowances, and mandated production technologies. In ranking these alternatives, economists tend to compare the instruments in terms of their cost-effectiveness.[1] However, policy makers often are at least as much concerned with how these options may differ in terms of the distribution of policy costs, since such differences importantly affect political feasibility.

Distributional impacts can be measured along several different dimensions — across household income groups, generations, geographic regions, and industries. The distribution across industries can be especially important, since industry groups often constitute a powerful political force. To the extent that industrial stakeholders wield significant political power, designing policies that achieve environmental goals while avoiding serious adverse impacts on key industries can enhance political feasibility.[2]

In this paper we examine how the costs of meeting given targets for pollution emissions change once one adds the requirement that the regulations cause no loss in profit in key pollution-related industries. In our investigation, this requirement is met by including, as part of the environmental policy, either lump-sum tax credits or reductions in capital tax rates to certain affected industries. The compensation issue has come to the fore in recent policy discussions. For example, several climate change policy bills recently introduced in the U.S. Congress (for example, one by Senator Jeff Bingaman of New Mexico and another by Senator Dianne Feinstein of California) contain very specific language stating that affected energy companies should receive just enough compensation to prevent their equity values from falling.[3]

Our analysis is in the spirit of a paper by Bovenberg et al. (2005), which examined how introducing a constraint on profit losses affects the costs of emissions taxes and quotas. The present paper goes beyond the previous paper by considering a wider range of policy instruments, focusing not only on emissions taxes but also on taxes on fuels (intermediate inputs associated with pollution) and two “command-and-control” policies — performance standards and mandated production technologies.

We apply a numerical general equilibrium model to compare economic costs under the different policies. We show that the overall gross cost[4] of achieving a given reduction in emissions can be understood in terms of two components: an *intrinsic abatement cost* and a *lump-sum compensation cost*. The former cost depends on the efficiency with which the policy instrument in question makes use of the three major channels for emissions reductions: input substitution, end-of-pipe treatment, and output reduction. The second cost reflects inefficiencies associated with providing the compensation to meet the no-profit-loss constraint when compensation takes the form of lump-sum payments.

As in earlier studies, we find that in the absence of a profits constraint, emissions taxes are less costly than fuel taxes and the command-and-control policies because they most effectively employ the various channels for emissions reductions. However, introducing the distributional constraint can reverse the overall cost rankings.[5] In particular, when compensation takes the form of lump-sum tax credits and the required amount of abatement is small or moderate, the command-and-control policies emerge as less costly than emissions taxes. At low levels of abatement, emissions taxes (and fuel taxes) have a significant disadvantage in terms of the costs of compensation — that is, the lump-sum compensation cost more than offsets the emissions tax’s advantage in terms of the intrinsic abatement cost. In contrast, when environmental policy is more stringent (that is, requires greater abatement), the emissions tax’s advantage by virtue of its lower intrinsic abatement cost becomes more important than its disadvantage in terms of the compensation cost. Thus, the relative costs of emissions taxes and the command-and-control instruments depend importantly on the extent of required abatement.

The rest of the paper is organized as follows: The next section presents theoretical background and intuition for how introducing distributional constraints could affect the rankings of policy costs. Section 3 describes the numerical model, while Section 4 presents and interprets the model’s results. Section 5 offers conclusions and caveats.

[1] See, for example, Tietenberg (1990), Stavins (1996), Goulder et al. (1999) and Fischer et al. (2003).

[2] Designing such policies also may have justification on the grounds of distributional equity: avoiding serious impacts on key industries helps assure that the policy burdens are spread more evenly over the population rather than imposed disproportionately on a relatively small population group.

[3] Another example is provided by a bill recently introduced by Senator Mike Crapo of Idaho. The bill, which has received bipartisan Senate support, provides compensation via tax credits to landowners complying with the Endangered Species Act.

[4] By “gross cost” we mean the cost before netting out the benefits from policy-induced environmental improvements.

[5] Our model does not consider all of the factors that may influence the cost rankings. In the final section of the paper we consider how some omitted factors might influence these rankings.

2. Theoretical background

Here we offer theoretical background relevant to the interpretation of results from our numerical model. This discussion is based on analytical results provided in our working paper, Bovenberg et al. (2006). That paper's analytical model is similar to the numerical model we use in this paper. It includes two primary factors of production – capital and labor – and two consumption goods. One of the consumption goods represents the polluting sector of the economy; the other represents goods that are produced without causing pollution. Cuts in pollution intensity can be accomplished through both input substitution and "end-of-pipe" emissions treatment. The model recognizes the imperfect mobility of capital, which is critical for considering the profit impacts of various policies. Finally, the model incorporates pre-existing taxes on capital and labor income and associated factor-market distortions. The presence of distortionary factor taxes implies that raising revenue to finance compensation exacerbates factor-market distortions and thus involves efficiency costs over and above the costs of abatement to the firms that reduce their emissions.

Consider now the economic impact of four alternative policies: a tax on omissions, a tax on fuel, a performance standard (a constraint on the ratio of emissions to output), and a technology mandate (a production process requirement in the form of a required ratio of emissions to the use of a fuel input). The four policies generally have revenue impacts, either directly or through their effect on factor tax receipts. Assume that the government adjusts factor tax rates in order to maintain revenues necessary to finance a constant level of expenditure on services provided to households. Hence the emissions tax and fuel tax policies, which yield gross revenues, generally involve reductions in factor taxes to remain revenue-neutral. Providing compensation to firms, however, necessitates an increase in government spending and therefore has the opposite influence on required factor tax rates.

2.1. Efficiency costs for policies without compensation

Let a policy's *intrinsic abatement cost* refer to its abatement cost in the absence of the compensation requirement. This cost is affected by the extent of abatement and the channels that the policy exploits for reducing emissions.

At initial (or incremental) abatement, all four of the policies have intrinsic abatement costs approaching zero. The intuition for the zero initial impact is that each channel for abatement – input substitution, end-of-pipe treatment, and output-demand reduction – involves infinitesimal costs at the first unit of abatement. A profit-maximizing firm equates the marginal benefits of additional emissions along any of these channels to the marginal cost of emissions. (The marginal benefit is the cost-saving from the reduced need to utilize a given channel.) In the absence of regulation, the marginal cost of emissions is zero. Hence the marginal benefit from an increment to emissions along any one of these channels is zero as well. Equivalently, the marginal cost of reducing emissions along any of these channels is zero.[6]

While the intrinsic efficiency costs of all four policies start out together at zero for initial abatement, these costs differ substantially as abatement becomes more extensive. As indicated in prior studies,[7] the emissions tax has an advantage over other policies in terms of these costs because it yields appropriate incentives for end-of-pipe treatment, input substitution, and output-demand reduction (from higher output prices).[8] The tax on the intermediate (fuel) input exploits only the channels of input substitution and output cuts. The command-and-control policies also exploit a subset of channels. In particular, the technology mandate primarily engages the end-of-pipe treatment channel and the performance standard includes both end-of-pipe treatment and input substitution. The rankings of the fuel tax, technology mandate, and performance standards in terms of the intrinsic efficiency cost thus depend on the relative ease of input substitution, end-of-pipe treatment, and output-demand reduction. This determines the relative opportunity cost of neglecting one or more of these channels. We explore this issue numerically below.

[6] The four policies also share the property that marginal (intrinsic) efficiency costs rise with the extent of abatement. Greater abatement requires increased use of some combination of the channels of input substitution, output-demand reduction, and end-of-pipe-treatment. If production functions are concave, greater input-substitution involves increasing marginal costs. Furthermore, convex utility (downward sloping demand curves) implies that greater output reduction entails increasing marginal welfare costs. Finally, end-of-pipe treatment typically involves rising marginal costs.

[7] See, for example, Goulder et al. (1999).

[8] The emissions tax also has some advantages along other dimensions. As discussed in several other studies (see, for example, Stavins, 1998 and Tietenberg, 1990), it can yield a more cost-effective allocation of abatement effort in the presence of heterogeneous firms, and it may offer more enduring incentives for technological innovation.

2.2. Efficiency costs for policies involving compensation

Efficiency costs differ significantly when the compensation requirement is imposed.

2.2.1. Compensation via lump-sum tax credits

When compensation takes the form of lump-sum tax credits, providing the compensation involves an efficiency cost because raising public funds to finance these credits is distortionary. We refer to this cost as the *lump-sum compensation cost*. Compensation via lump-sum tax credits introduces a cost over and above the intrinsic abatement cost.

Under the emissions tax and fuel tax, the lump-sum compensation cost is present even for incremental abatement because emissions reductions achieved through taxes require firms to pay the tax for whatever emissions they continue to generate (under the emissions tax) or for whatever amount of fuel they continue to utilize (under the fuel tax). Since the associated income transfer from capital owners to the government is non-incremental, the magnitude of the required tax credit to compensate capital owners is significant as well. This produces a first-order efficiency cost, approximated by the product of the required credit and the marginal excess burden.

Under the command-and-control policies (performance standard and technology mandate), the lump-sum compensation cost is lower than under the two tax policies. The command-and-control policies effectively include subsidies to the use of fuel or to output of the pollution-intensive good.[9] Indeed, under these policies the polluting industries do not transfer fiscal resources to the government. Hence they require little or no compensation.

These considerations suggest that the rankings of the four policies can change when the compensation requirement is imposed and compensation takes the form of lump-sum tax credits. In particular, the emissions tax could lose its cost-advantage once the compensation requirement is imposed. The potential of command-and-control policies to involve lower costs than the emission tax is especially great at low levels of abatement. For at such levels, the command-and-control policies suffer relatively little disadvantage in terms of the intrinsic abatement cost — indeed, as noted above, the intrinsic abatement costs of all four policies become infinitesimal as abatement approaches zero. At the same time, the command-and-control policies involve significantly smaller lump-sum compensation costs. This means that the overall abatement costs of the command-and-control policies are smaller than those of the emissions tax (and fuel tax) at low levels of abatement.

However, when abatement is more extensive, the command-and-control policies could lose their overall cost-advantage. The reason is that these policies have a disadvantage in terms of the intrinsic abatement cost. This disadvantage grows as the amount of abatement increases. Thus, these command-and-control policies involve lower overall costs at low levels of abatement, but could exhibit higher overall costs when abatement is more extensive. Section 4 applies the numerical model to explore the potential for a switch in the cost rankings.[10]

2.2.2. Compensation via cuts in marginal tax rates on sector-specific capital

Now consider the case where compensation is achieved through cuts in marginal tax rates on capital employed in the polluting industries. In this case, there is no lump-sum compensation cost, but compensation distorts the channels through which abatement can be achieved. In particular, lower marginal capital taxes in the polluting industries reduce the marginal costs of production, thereby yielding lower output prices and higher demand. Similarly, lower capital tax rates boost demand for the fuel input (insofar as fuel and capital are complements in production). As a result, the efficacy of the output-demand reduction and input substitution channels is reduced, and firms have to rely more on end-of-pipe treatment to cut pollution to the given abatement target. Since less efficient pollution abatement implies higher marginal costs, achieving a given level of emission cuts involves higher costs than in the absence of a compensation requirement.

It is difficult to determine *a priori* how this form of compensation affects differences in overall costs across the four policy instruments. We explore the potential for impacts on the cost rankings in the numerical model.

[9] See Fullerton and Heutel (2006) for an analysis comparing the long-run incidence of various command-and-control policies.

[10] In the present study, the higher cost of emissions taxes arises when compensation is lump-sum in nature. This result is reminiscent of earlier studies that have shown how emissions taxes can be more costly than other instruments when government budget balance (as opposed to firms' compensation) must be achieved through lump-sum transfers. (See Parry and Oates, 2000; Goulder et al., 1999 and Fullerton and Metcalf, 2001). In all of these studies, the use of lump-sum payments (and the associated need to finance such payments through distortionary taxes) lies behind the higher cost of the emissions tax.

3. A numerical model

Here we develop and apply a numerical model in order to obtain quantitative results. We briefly describe the model here; a complete description is in a technical appendix, available from www.stanford.edu/~goulder.

The formal structure of this numerical model is quite similar to that of the analytical model in Bovenberg et al. (2006). There are two primary factors of production – capital (K) and labor (L) – with capital immobile across industries and labor mobile. The economy involves three industries: an upstream industry that produces an intermediate good X whose use is associated with pollution, a downstream industry that produces a final good Y and generates pollution emissions, and another final good industry that produces a clean, final good C without generating any pollution. Industry Y's emissions depend on the extent to which it employs the intermediate input X. In addition to cutting output, industry Y can reduce these emissions by changing its input mix (substituting labor or capital for X) and by engaging in end-of-pipe treatment. One can think of the intermediate input X as a fossil fuel and regard the downstream industry Y as an industry such as electricity that burns the fuel and produces pollution.

3.1. Structure

3.1.1. Production and factor mobility

We adopt constant-elasticity-of-substitution (CES) functional forms for the production functions for the intermediate input X and the final goods Y and C. Demand for the final goods comes from the households and for use in end-of-pipe treatment. Demand for the intermediate good X comes only from the Y industry. Each industry employs labor and capital as inputs, and industry Y employs the intermediate input X as well. Specifically:

$$C = \gamma_C \left[\alpha_C K_C^{\frac{\sigma_C - 1}{\sigma_C}} + (1 - \alpha_C) L_C^{\frac{\sigma_C - 1}{\sigma_C}} \right]^{\frac{\sigma_C}{\sigma_C - 1}}, \tag{1}$$

$$X = \gamma_X \left[\alpha_X K_X^{\frac{\sigma_X - 1}{\sigma_X}} + (1 - \alpha_X) L_X^{\frac{\sigma_X - 1}{\sigma_X}} \right]^{\frac{\sigma_X}{\sigma_X - 1}}, \tag{2}$$

$$Y = \gamma_Y \left[\alpha_Y V^{\frac{\sigma_Y - 1}{\sigma_Y}} + (1 - \alpha_Y) L_Y^{\frac{\sigma_Y - 1}{\sigma_Y}} \right]^{\frac{\sigma_Y}{\sigma_Y - 1}}, \tag{3}$$

with

$$V = \gamma_V \left[\alpha_V K_Y^{\frac{\sigma_V - 1}{\sigma_V}} + (1 - \alpha_V) X^{\frac{\sigma_V - 1}{\sigma_V}} \right]^{\frac{\sigma_V}{\sigma_V - 1}}, \tag{4}$$

where σ_Y, σ_X, σ_C, and σ_V represent the elasticity of substitution among inputs in the various industries. K and L (with subscripts to represent each industry) are the quantity of capital and labor employed. The production function for good Y is weakly separable. In particular, the marginal rate of substitution between the intermediate input X and capital K_Y does not depend on industry-specific employment L_Y; the intermediate input and capital first yield the composite V, which in turn is combined with labor to yield output Y.[11]

An important feature of the model is the imperfect mobility of capital across sectors. This implies that the profit impacts of an unanticipated policy shock will not be uniformly spread across capital owners in all industries, because capital cannot costlessly move to the sectors with the highest returns after the shocks. In particular, emissions-reduction policies can cause an especially large decline in the rate of return to capital in pollution-related industries, with associated losses of capital income. In the model, when policies include compensation this is just enough to offset the loss of capital income to original owners of capital in these industries.

[11] These separability assumptions are consistent with empirical work (see, e.g., Jorgenson and Wilcoxen, 1993a,b) suggesting that capital is a complement to energy (or fuel) inputs. For an analytical treatment of more general production structures, see Fullerton and Heutel (2006).

To capture capital's imperfect mobility, we employ the transformation function:[12]

$$K = \gamma_K \left[\alpha_K K_X^{\frac{\sigma_K - 1}{\sigma_K}} + \beta_K K_Y^{\frac{\sigma_K - 1}{\sigma_K}} + (1 - \alpha_K - \beta_K) K_C^{\frac{\sigma K - 1}{\sigma_K}} \right]^{\frac{\sigma_K}{\sigma_K - 1}}, \tag{5}$$

where K represents the economy-wide stock of capital and the parameter σ_K controls the curvature of the function. We employ negative values for σ_K so that the transformation function is bowed out from the origin. Successive increments to the supply of any given type of capital thus require ever-larger sacrifices of other types of capital, in keeping with increasing marginal adjustment costs. In contrast to capital, labor is perfectly mobile across industries.

3.1.2. Emissions

Emissions are generated by the downstream industry Y. These are a function of that industry's use of fuel (X) and the resources devoted by that industry to end-of-pipe treatment. We adopt the following emissions function:

$$\frac{E}{X} = \gamma_E \left[1 + \beta_E \left(\frac{m(Y_A, C_A)}{X} \right)^{\rho_E} \right]^{\frac{-1}{\rho_E}} \quad \beta_E > 0; \quad 0 < \rho_E < 1, \tag{6}$$

where the function $m(Y_A,C_A)$, representing resources devoted to end-of-pipe treatment, is a CES composite of the two final goods. The emissions ratio E/X above can be represented as $\gamma_E f(m(\cdot)/X)$. The function $f(\cdot)$ has the following desirable properties:

- $f'(0) \Rightarrow -\infty$. This first unit of end-of-pipe treatment is very productive in cutting emissions. Accordingly, end-of-pipe treatment is positive if emissions are constrained (implying a positive shadow price of pollution permits)
- $f(\infty)=0$. Pollution is eliminated completely if end-of-pipe treatment is very large.
- $f(0)=1$. Without any end-of-pipe treatment, pollution remains finite.

3.1.3. Household utility and income (goods demand and factor supply)

Households maximize utility, which depends on labor and capital supplied (to generate income) and on consumption of the two final goods Y and C. We model household utility with the CES function:

$$U = \left(\alpha_N N^{\frac{\sigma_U - 1}{\sigma_U}} + \alpha_Z Z^{\frac{\sigma_U - 1}{\sigma_U}} \right)^{\frac{\sigma_U}{\sigma_U - 1}}, \tag{7}$$

where N is a CES composite of Y_H and C_H (the quantities of goods Y and C devoted to household consumption):[13]

$$N = \left(\alpha_{NY} Y_H^{\frac{\sigma_N - 1}{\sigma_N}} + \alpha_{NC} C_H^{\frac{\sigma_N - 1}{\sigma_N}} \right)^{\frac{\sigma_N}{\sigma_N - 1}}. \tag{8}$$

Z is a CES composite of labor supply and aggregate capital supply:

$$Z = \left(\alpha_{ZL} \left(\overline{L} - L \right)^{\frac{\sigma_Z - 1}{\sigma_Z}} + \alpha_{ZK} \left(\overline{K} - K \right)^{\frac{\sigma_Z - 1}{\sigma_Z}} \right)^{\frac{\sigma Z}{\sigma_Z - 1}}, \tag{9}$$

where $\overline{L}$ and $\overline{K}$ represent the maximum potential labor supply (endowment of labor time) and capital supply, respectively.[14] The elasticities σ_U, σ_N, and σ_Z represent the ease of substitution between the composites N and Z,

[12] This supply function can be interpreted as a multi-product firm that employs aggregate capital as an input to produce three outputs: namely, the three capital stocks K_i (i=X, Y, C).

[13] For simplicity, the parameters of the function producing the composite of Y_H and C_H are the same as in the function producing the composite of Y_A and C_A in the emission function.

[14] In a fully dynamic model, the cost of supplying capital is current consumption foregone when resources are devoted to investment instead of consumption. We include capital in the utility function to account for the cost of capital supply in our static model, which does not deal with investment explicitly. An alternative interpretation of K is as highly specialized labor which, in contrast with other labor, is imperfectly mobile across sectors.

goods Y and C, and factor supplies L and K, respectively. Note that this utility function does not account for the welfare impact of changes in environmental quality. All of the policy costs described in the results below should therefore be regarded as gross costs: they do not net out the benefits associated with policy-induced environmental improvements.

Households earn income through the supply of labor and capital. They also receive a fixed real transfer from the government, G. In the policy cases where industry compensation is provided via lump-sum tax credits, households (owners of firms) receive an additional transfer, S. Factor income (as well as the transfer S when present) is taxed at the same proportional rate T. The household budget constraint is given by:

$$P_Y Y_H + P_C C_H = (1-T)(WL + RK + S) + P_N G,$$

where P_Y and P_C are the consumer prices of Y and C, respectively, P_N is the ideal price index for consumer goods and W stands for the wage rate. R denotes the ideal price index associated with the transformation function (5) so that RK is total pre-tax receipts from capital. In the policy cases where compensation is provided via marginal subsidies to capital, RK includes those subsidies.

3.1.4. The government budget

The government levies factor taxes and introduces the environmental policies and compensation described above. All revenues are returned to the private sector through lump-sum credits or marginal cuts in factor taxes. The government's budget constraint is:

$$P_N G + S(1-T) + S_{KX} K_X + S_{KY} K_Y = \underbrace{T(WL + RK)}_{\text{factor tax revenue}} + \underbrace{T_E E + T_X X + T_Y Y}_{\text{environmental tax revenue}},$$

where S_{KX} and S_{KY} are the subsidies used in the case of compensation via marginal subsidies to capital in the polluting industries. The variables T_E, T_X, and T_Y respectively refer to the tax (as applicable) on emissions E and on the output from industries X and Y. Total government revenue, shown on the right-hand side, comes from the various taxes.

3.2. Policy experiments

We explore four policies that achieve given targets for pollution abatement. Table 1 lists the policies considered and summarizes how they are implemented in the model. The emissions tax and fuel (intermediate input) tax policies involve T_E and T_X, respectively. The technology mandate is a constraint on the ratio E/X, while the performance standard is a constraint on the ratio E/Y. As shown by Fullerton and Metcalf (2001), these two policies are equivalent to revenue-neutral tax-subsidy combinations. We make use of these equivalences in modeling the two policies. Specifically, we represent the technology mandate as a revenue-neutral combination of a subsidy to the intermediate input (i.e., a negative value for T_X) and a tax on emissions $T_E>0$:

$$T_X X + T_E E = 0. \tag{10}$$

Similarly, we represent the performance standard as a revenue-neutral combination of an output subsidy (i.e., a negative value for T_Y) and an emissions tax $T_E>0$:

$$T_Y Y + T_E E = 0. \tag{11}$$

Compensation is provided either through tax credits or sector-specific subsidies to capital. In the first case, an amount equal to S is transferred to capital owners to offset the change in capital income or equity value in the X and Y industries. In the second case, the government provides the subsidies S_{KX} and S_{KY} to the use of capital in the X and Y sectors such that equity value is restored.

3.3. Equilibrium conditions

The requirements of the general equilibrium are that (1) household supply of labor must equal aggregate labor demand by firms, (2) demand for capital by each industry i ($i=X, Y, C$) must equal the quantity supplied to that industry, (3) pollution emissions must equal the pollution level stipulated by environmental policy, and (4) government revenue

Table 1
Policies and their implementation in the numerical model

Policy	Instrument for achieving…		
	Emissions target	EVN constraint	Government budget balance
Emissions tax	Tax on E	Sector-specific lump-sum tax credit or sector-specific reductions in capital tax rates (*all policies*)	Economy-wide equi-proportionate cuts in capital and labor tax rates (*all policies*)
Input (fuel) tax	Tax on X		
Technology mandate (constraint on E/X)	Revenue-neutral[a] combination of tax on E and subsidy to X.		
Performance standard (constraint on E/Y)	Revenue-neutral[a] combination of tax on E and subsidy to Y		

[a] Revenue-neutral at the industry level. This neutrality is gross of changes in revenues stemming from impacts on the bases of other taxes.

must equal real transfers to households. The before-tax wage is the numeraire. The model identifies the primary "prices" that cause these four types of equilibrium conditions to be met. These are the equilibrium rental prices for capital, the emissions tax rate, and the marginal factor tax rate T. These prices determine output prices (and output demands) and the real wage. Walras's law implies that the labor market clears when all the other markets clear.

For the technology mandate and performance standard, a further numerical equilibrium condition is introduced. As mentioned above, these policies are modeled as revenue-neutral combinations of taxes on emissions and subsidies to either intermediate input X (technology mandate) or output Y (performance standard). For these policies, the model adds the relevant revenue-neutrality condition, and solves for the subsidy rate that meets that condition.[15]

3.4. Data

We apply the numerical model to the U.S., letting Y represent the electricity industry and C the other U.S. final goods industries. X refers to the industry producing (extracting) fossil fuels — coal, crude petroleum and natural gas. The use of these fuels by the electricity (Y) industry leads to emissions. We focus on control of sulfur dioxide (SO_2) emissions.[16]

Table 2 indicates the inter-industry flows in our data set. These flows derive from the U.S. Commerce Department Bureau of Economic Analysis's *Benchmark Input & Output Tables for* 1992. The emissions data come from the 1992 column of Table 12.6 of the Energy Information Agency's *Annual Energy Review* 1999.

Table 3 displays the model's parameters. The elasticities of substitution in production are taken from the disaggregated general equilibrium data set developed by Barreto et al. (2002). For the Y industry, we calibrate the model to generate production and abatement elasticities consistent with those from the detailed "HAIKU" model of the U.S. electricity industry developed at Resources for the Future. The substitution elasticities σ_Y and σ_V imply that, compared to capital, labor is a much better substitute for X. The elasticities reflect the substitution patterns leading to emissions reduction in the HAIKU model.

The capital adjustment parameter σ_K is chosen so as to yield capital responses roughly consistent with findings from a survey by Chirinko et al. (2002) indicating that the elasticity of investment with respect to the cost of capital is in the range of 0.25–0.4.

We calibrate the model to generate uncompensated and compensated labor supply elasticities of 0.15 and 0.4, respectively.[17] This is consistent with surveys by Fuchs et al. (1998) and Russek (1996). Together, these two elasticity targets yield the values for the elasticity of substitution between leisure and capital and the benchmark ratio of total (labor plus leisure) time to labor time. These values imply a marginal excess burden of 0.24 for labor taxes. Capital

[15] These policies are revenue-neutral in the sense that the gross revenue earned by the emissions tax just equals the revenue cost of the subsidy. However, these policies generally have an impact on the economy's gross revenue because they affect the base of the factor tax.

[16] While our model calibrates the costs of end-of-pipe treatment to the control of SO_2 emissions, the emerging technology for "carbon separation and capture" is beginning to make end-of-pipe treatment relevant in the case of carbon dioxide emissions as well.

[17] To calibrate the model to these labor supply parameters, we numerically solve the household's utility-maximization problem with given prices and observe the change in labor supply resulting from a change in the after-tax wage. We solve this as a constrained optimization problem, where the amount of capital supplied is fixed. To calculate the compensated elasticity, we also alter the household's income so that utility remains unchanged despite the change in the after-tax wage.

Table 2
Benchmark input–output flows for the numerical model[a]

	Use of input by industry...			Total receipts to each input	Endowments[c]
	X	*Y*	*C*		
Input[b]:					
X	0.0	27.1	0.0	27.1	
L	2.6	11.8	1765.3	1779.7	5249.8
K	13.7	44.0	712.4	770.1	2271.5
Factor taxes	10.8	48.0	1651.8	1710.6	
Total input payments by each industry	27.1	130.9	4129.5		
SO_2 *emissions*[d]		15.2			

Sources: Except for the emissions data, these flows are based on the Department of Commerce Bureau of Economic Analysis's *Benchmark Input & Output Tables for* 1992. The emissions data are from Table 12.6 of the Energy Information Agency's *Annual Energy Review* 1999.
[a] In billions of year—2000 dollars per year except where otherwise noted.
[b] Inputs of labor and capital are net of factor taxes.
[c] Endowments correspond to *L* and *K* in Eq. (9) of text.
[d] Millions of tons per year.

supply elasticities are set equal to labor supply elasticities.[18] Hence the same tax rate T on both capital and labor income is optimal.[19]

4. Simulation results

4.1. Cost-effectiveness and incidence — No EVN constraint

We apply the model to examine the impacts of emissions taxes, performance standards, technology mandates, and fuel taxes.[20] Our first experiments assess the efficiency and incidence impacts of these instruments in the absence of compensation to preserve profits. As in some prior studies, we shall often refer to the compensation condition as the equity value neutrality (EVN) requirement.[21]

Fig. 1 compares the policy costs, as measured by the negative of the equivalent variation. The emissions tax is the most cost-effective, followed by the two "command-and-control" policies (the technology mandate and performance standard). The fuel tax is the least cost-effective and is omitted from the figure for scale — its costs may be found in Table 4. As discussed in Section 2, the emissions tax is the most cost-effective instrument because it efficiently exploits all three channels for abatement: input substitution, end-of-pipe treatment, and output reduction. Thus it involves the lowest intrinsic abatement cost. The other policies fail to exploit at least one of these channels. The performance standard – equivalent to the combination of emissions tax and subsidy to output – leads to inefficiently low output prices and thus makes relatively little use of the output-reduction channel. Similarly, the technology mandate – equivalent to the combination of an emissions tax and a subsidy to the fuel input – yields inefficiently low incentives for substitution away from the pollution-generating fuel, as well as for output reduction (the subsidy to the input leads

[18] This is accomplished in calibration by setting the ratio $\bar{K}/K$ equal to the ratio $\bar{L}/L$.
[19] A more complex structure might incorporate a utility function with which uniformity of factor tax rates is not optimal, and/or a tax system that did not include uniform rates. Such complications would not be particularly useful in the present study, since they would not be expected to exert significant influences on the industry-distributional effects of pollution policies or the costs of compensation.
[20] In the absence of uncertainty, policies involving tradable emissions permits are equivalent to various emissions tax policies. If permits are initially allocated through an auction, an emissions tax of T_E is equivalent to a system involving auctioned permits that yields a permit price equal to T_E. Both policies will lead to the same economic outcomes, including the extent of abatement. A system of tradable permits in which the permits are initially allocated free is equivalent to an emissions tax with a lump-sum rebate equal to the total tax revenues.
[21] In a dynamic analysis, the impact of a policy on owners of a given firm can be measured as the change in the firm's equity value. "Equity value neutrality" is thus the condition that capital owners suffer no change in the value of their capital. Although the present paper's model is static, we continue to use the term "equity value neutrality" to match the terminology in Bovenberg and Goulder (2001) and Bovenberg et al. (2005).

Table 3
Central case parameter values

Parameters for Y industry		
β_E	Ease of end-of pipe treatment-scale parameter	2.0
ρ_E	Ease of end-of-pipe treatment-curvature parameter	0.6
σ_Y	Elasticity of substitution between V and L in production of Y	0.75
σ_V	Elasticity of substitution between X and K in production of V	0.15
Parameters for X and C industries		
σ_X	Elasticity of substitution between K and L in production of X	1.0
σ_C	Elasticity of substitution between K and L in production of C	1.0
Other production-related parameters		
σ_K	Ease of capital movement	−1.0
Utility function parameters		
σ_U	Elasticity of substitution between N (C–Y composite) and Z (L–K) composite	0.66
σ_N	Elasticity of substitution between C and Y	0.9
σ_Z	Elasticity of substitution between L and K	0.9

to output prices that are lower than those under the emissions tax). The fuel tax provides no incentive for end-of-pipe treatment. The exceptionally high cost of the fuel tax in our model indicates that, under central values for parameters, the absence of the end-of-pipe channel is especially important.[22]

Table 4 indicates the price impacts of each policy, for abatement of 10, 25, and 75%. The performance standard leads to the smallest change in the demand (consumer) price of the downstream good Y because it is equivalent to an emissions tax and output subsidy. Indeed, the price of that good falls (slightly) in the case of 10% abatement. The technology mandate (which effectively subsidizes the fuel input to the downstream good industry) also has a relatively small impact on the price of the downstream good. The emissions tax and fuel tax yield the largest impacts on the price of the downstream good Y. The impact is especially large in the case of the fuel tax. Since this policy does not exploit the channel of end-of-pipe treatment, a very high fuel tax is needed to induce sufficient input substitution to meet a given abatement target. This high tax leads to a large increase in the cost of the fuel input and in the price of the output Y.

Table 4 also displays the incidence (i.e., profit and wage) impacts of the different policies. Their subsidy components cause the technology mandate and performance standard to generate the smallest adverse profit impacts on the downstream industry Y. They also exert the smallest adverse impacts on profits to the upstream industry X, reflecting the fact that these policies reduce only slightly the demand for the upstream good. The upstream industry X faces the smallest loss of profit under the technology mandate, in keeping with the mandate's implicit subsidy to that industry, while the downstream industry Y experiences the smallest profit loss under the performance standard, reflecting that policy's implicit subsidy to that industry. The fuel tax imposes the largest burden on the upstream and downstream industries, reflecting the need to impose a relatively high tax rate to reach given levels of abatement when the channel of end-of-pipe treatment is not employed.

4.2. Cost-effectiveness in the presence of the EVN constraint

4.2.1. Compensation via lump-sum tax credits

We now examine the relative costs when the policies must include compensation to the pollution-related industries. These costs depend on the way in which compensation is provided. We first explore the costs when compensation is provided through lump-sum tax credits to both of the pollution-related industries: that is, to both X and Y.

[22] In the central case, the parameter r_E (calibrated from the HAIKU model) implies fairly elastic response of end-of-pipe treatment to the price of emissions. Hence, the fuel tax's failure to engage the channel of end-of-pipe treatment is a significant disadvantage in this case.

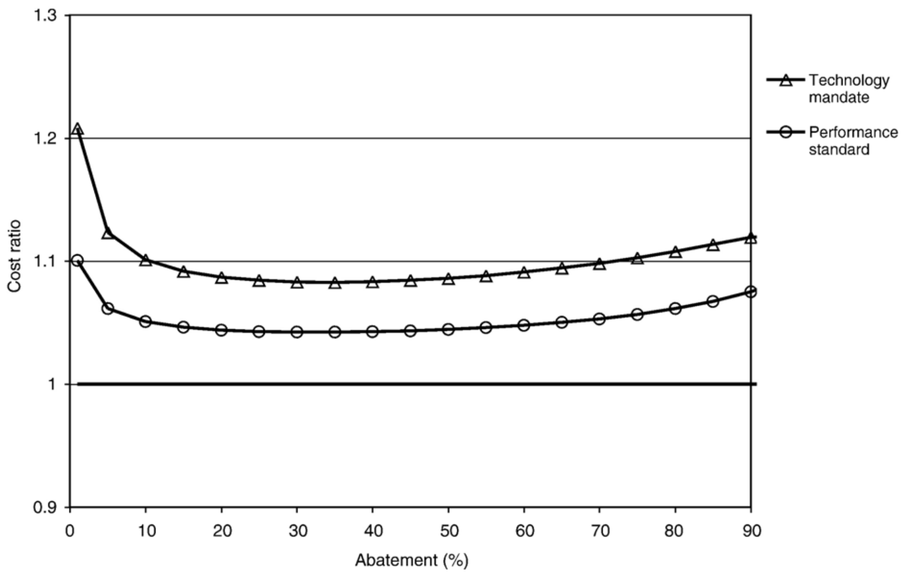

Fig. 1. Policy costs relative to emissions tax cost — no compensation.

Table 5 compares, for each policy, the aggregate policy costs in the presence and absence of the EVN constraint with an abatement target of 25%. The additional costs implied by the constraint are largest for the emissions tax and (especially) the fuel tax because these policies require the most compensation (in the form of tax credits). To preserve budget balance, the government must finance the tax credits by significantly increasing tax rates on factors of production. This raises the costs of the emissions tax and fuel tax considerably relative to the case without EVN. In contrast, under the command-and-control policies, much less compensation is needed, so for these policies the

Table 4
Impacts of alternative policies (no industry compensation requirement)

Policy experiment	Tax on emissions			Tax on fuel			Technology mandate			Performance standard		
Percent abatement	10	25	75	10	25	75	10	25	75	10	25	75
Tax on E or X[a]	0.10	0.26	3.87	0.54	1.93	42.52	0.11	0.29	4.99	0.10	0.27	4.44
Fraction abatement from EOP	0.88	0.89	0.76	0.00	0.00	0.00	0.99	0.98	0.89	0.93	0.93	0.83
Aggregate cost (as % of income)	0.001	0.008	0.160	0.011	0.077	1.387	0.001	0.008	0.176	0.001	0.008	0.169
Price and quantity impacts												
% change in supply price of X	−0.89	−2.13	−13.58	−7.52	−19.15	−61.92	−0.06	−0.32	−6.39	−0.50	−1.26	−9.70
% change in demand price of X	−0.89	−2.13	−13.58	42.15	136.29	1417.83	−5.47	−12.46	−82.90	−0.50	−1.26	−9.70
% change in quantity of X	−1.19	−2.85	−17.89	−10.00	−25.00	−75.00	−0.08	−0.44	−8.52	−0.68	−1.71	−12.92
% change in supply price of Y	0.67	1.63	12.99	6.40	20.45	210.79	0.04	0.24	5.32	1.14	2.69	19.35
% change in demand price of Y	1.66	3.95	24.90	14.27	36.45	100.48	0.10	0.55	10.79	−0.06	0.16	7.25
% change in quantity of Y	−0.58	−1.42	−10.40	−5.32	−15.21	−64.37	−0.04	−0.22	−4.70	0.01	−0.11	−4.21
Incidence[b]												
Change in profit to X	−0.14	−0.34	−2.20	−1.20	−3.04	−9.70	−0.01	−0.05	−1.07	−0.08	−0.21	−1.59
As a % of EV	172%	71%	22%	183%	64%	11%	10%	10%	10%	93%	41%	15%
Change in profit to Y	−0.22	−0.54	−3.99	−2.00	−5.79	−25.81	−0.02	−0.09	−1.85	0.02	−0.02	−1.50
As a % of EV	265%	111%	40%	305%	121%	30%	17%	17%	17%	−20%	3%	14%
Change in profit to X and Y	−0.36	−0.88	−6.19	−3.20	−8.83	−35.50	−0.02	−0.14	−2.92	−0.06	−0.22	−3.09
As a % of EV	438%	182%	62%	487%	185%	41%	27%	27%	27%	73%	44%	30%
Change in profit to C	0.05	0.03	−1.68	0.42	0.22	−19.39	−0.02	−0.12	−2.55	−0.03	−0.13	−2.57
Change in wage income	0.23	0.36	−2.38	2.03	3.14	−41.06	−0.05	−0.26	−5.53	0.00	−0.15	−4.92

[a] Tax on emissions is in thousands of dollars per ton; tax on fuel is in percent.
[b] Units in this panel are billions of dollars unless indicated otherwise.

Table 5
Effects of policies with and without EVN constraint (emissions reduced by 25% in all cases)

	Tax on emissions	Tax on fuel	Technology mandate	Performance standard
Aggregate cost without EVN[a]	0.0078	0.0767	0.0084	0.0081
Compensation needed for EVN				
For X as % of profit	2.50	22.26	0.40	1.51
For Y as % of profit	1.22	13.17	0.20	0.04
Total as % of profit	1.52	15.33	0.25	0.38
EVN via lump-sum tax credits				
Aggregate cost with EVN[a]	0.0112	0.1081	0.0090	0.0090
Increase in cost[a]	0.0034	0.0313	0.0006	0.0009
EVN via cuts in factor tax rates				
Aggregate cost with EVN[a]	0.0083	0.1633	0.0086	0.0084
Increase in cost[a]	0.0005	0.0866	0.0002	0.0003
Tax rates used to achieve EVN				
Capital tax rate for X[b]	34.86	−281.62	39.29	35.94
Capital tax rate for Y[b]	38.78	−26.58	39.82	40.65

[a] Expressed as a percent of benchmark income.
[b] Net of the subsidy used for EVN. All capital taxes are set to 40% in the benchmark.

marginal factor tax rates in the cases with and without EVN are not much different. Hence, the added efficiency cost of the EVN constraint is smaller under command and control.

The EVN requirement can reverse the rankings of the various instruments in terms of overall costs (which include the lump-sum compensation cost). As shown in Fig. 2, the EVN constraint makes the costs of the emissions tax higher than those of the command-and-control policies, for all except very high amounts of abatement. The emissions tax's need for more compensation (at any level of abatement) implies larger compensation-related costs relative to those of the other policies. The relatively high compensation costs work against the emissions tax's advantage in terms of the intrinsic abatement cost. Fig. 2 reveals that, at low and moderate levels of abatement, the emissions tax's disadvantage in terms of compensation costs overwhelms its advantage in terms of intrinsic abatement costs. Only at very high levels of abatement does the intrinsic abatement advantage dominate. When very high levels of abatement are called for, the

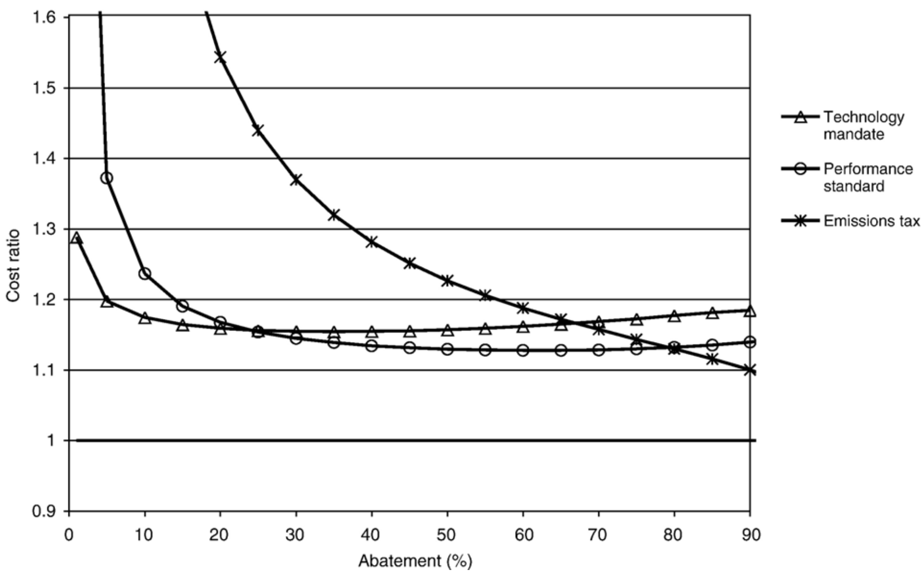

Fig. 2. Policy costs relative to emissions tax without compensation — compensation via lump-sum tax credits.

other policies' neglect of at least one important abatement channel ultimately leads to substantial costs that offset their advantages related to compensation. Economists have long considered emissions taxes as a more cost-effective instrument than command-and-control policies. These results indicate that the need for compensation can reverse the rankings in terms of cost-effectiveness.

At low levels of abatement, the compensation requirement also reverses the rankings between the two command-and-control policies. At less than 25% abatement, the performance standard now emerges as more costly than the technology mandate. This reflects the need for greater compensation under the performance standard. Intuitively, under the performance standard a substantial part of the implicit subsidy (on the final good) is enjoyed by final consumers rather than owners of capital in the polluting industries. In the case of a technology mandate, in contrast, the implicit subsidy (on the intermediate input provided by the upstream industry to the downstream industry) is better targeted at the specific production factors in the two industries. Thus, at low levels of abatement the rankings between the emissions tax, performance standard and technology mandate are completely reversed when the EVN constraint is imposed.

4.2.2. Compensation via industry-specific cuts in capital tax rates

We now examine the relative costs when compensation is achieved through reductions in the marginal rates on capital income in the X and Y industries. The bottom set of rows in Table 5 shows the results from these experiments. The required levels of compensation under the various environmental policies are very similar to those in the case where industries were offered tax credits.

Table 5 reveals how the choice of compensation method affects the costs of the various policies. For the command-and-control policies, the choice of compensation method has relatively little impact on the efficiency cost, since the compensation requirements of these policies are relatively small. In contrast, for the emissions tax, the choice of compensation method significantly affects the policy's cost, since compensation requirements are larger under this policy.

Fig. 3 compares the costs of different policies in the case where EVN is accomplished through marginal rate cuts. A comparison with Fig. 1 indicates that each policy's costs are higher than in the case without compensation, while policy rankings are unchanged. These results indicate it is more efficient to protect owners of industry-specific capital through subsidies on this capital (as is done in the case of an emissions tax with sector-specific cuts in capital taxes) than through implicit subsidies on the output of the upstream industry (as in the case of a technology mandate) or the downstream industry (as in the case of a performance standard).

We also considered the relative costs of the two different compensation methods, holding fixed the choice of environmental policy instrument. In general, we found that marginal rate cuts involve lower costs than lump-sum tax credits at low levels of abatement, but higher costs at high abatement levels. This squares with the theory outlined in Section 2. Capital tax cuts reduce the effectiveness of the input substitution and output-demand channels, and thus

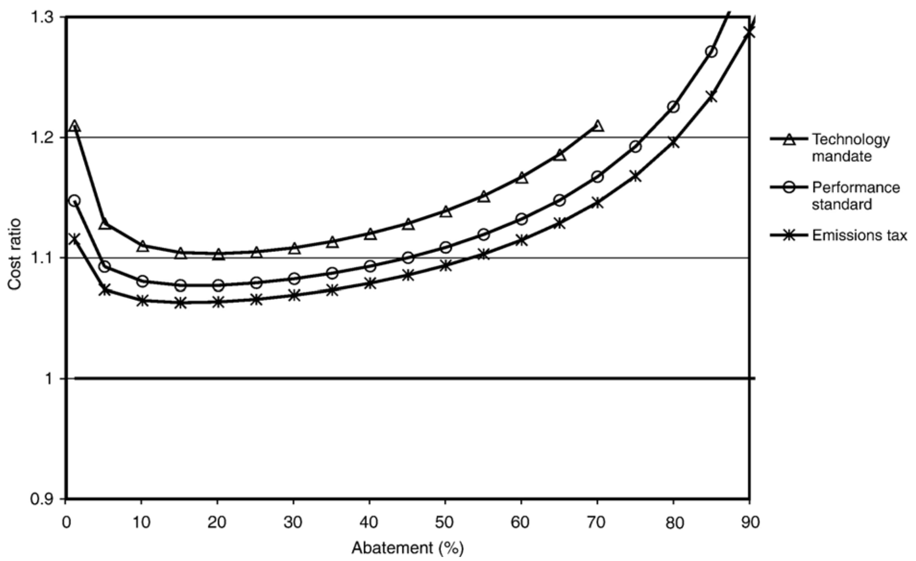

Fig. 3. Policy costs relative to emissions tax without compensation — compensation via marginal capital tax rate cuts.

result in less efficient pollution abatement (a higher intrinsic abatement cost). Inefficient abatement is especially important when the abatement target is stringent. For example, under a fuel tax, the cost of compensation through marginal rate cuts is lower than the cost through tax credits if the required abatement is less than 10%, but the cost becomes larger if greater abatement is called for. Similarly, under the emissions tax, the cost with compensation through marginal rate cuts overtakes the cost through lump-sum compensation once the abatement requirement exceeds 71%.

4.3. Sensitivity analysis

Tables 6 and 7 display the sensitivity of our results to changes in key parameters. In Table 6, which focuses on abatement levels of 25%, the first column of numbers displays the efficiency cost of the emissions tax in the absence of compensation. The remaining columns indicate the ratio of efficiency costs for the policy in question to the cost in the first column. For each of the four policy instruments considered, we show these ratios both for the no-compensation case and for the case with compensation via lump-sum tax credits. Table 7 indicates the critical levels of abatement at which the efficiency rankings of policies change.

4.3.1. End-of-pipe treatment

Higher values for the parameter β_E imply greater ease of end-of-pipe treatment; when β_E is zero, end-of-pipe treatment is not possible (the ratio of emissions to fuel use is fixed). Table 6 shows that the cost of abatement rises and

Table 6
Policy costs under alternative parameter values

	Equivalent variation (EV) at 25% abatement	Ratio of EV at 25% abatement to EV in left-most column							
	Emissions tax	Emissions tax		Fuel tax		Technology mandate		Performance standard	
	No EVN	No EVN	With EVN	No EVN	With EVN	No EVN	With EVN	No EVN	With EVN
Central case	0.0078	1.000	1.439	9.885	13.924	1.084	1.156	1.043	1.154
β_E (end-of-pipe treatment ease)									
Very low (0.0)	0.0767	1.000	1.409	1.000	1.409	n/a	n/a	2.260	2.424
Low (1.0)	0.0202	1.000	1.425	3.791	5.341	1.243	1.325	1.118	1.231
High (4.0)	0.0026	1.000	1.447	29.139	41.047	1.028	1.096	1.014	1.125
σ_K (capital adjustment costs)									
Very low (−100.0)	0.0074	1.000	1.037	7.298	7.551	1.119	1.130	1.066	1.082
Low (−4.0)	0.0075	1.000	1.188	8.060	9.485	1.106	1.141	1.058	1.111
High (−0.25)	0.0080	1.000	1.705	13.462	22.120	1.059	1.168	1.026	1.187
σ_N (elasticity of demand for Y)									
Low (0.45)	0.0079	1.000	1.303	12.959	16.388	1.070	1.121	1.027	1.126
High (1.8)	0.0076	1.000	1.598	7.864	12.384	1.101	1.198	1.062	1.186
σ_U (factor-supply elasticity)									
Low (0.33)	0.0069	1.000	1.219	9.889	11.907	1.085	1.120	1.043	1.098
High (1.32)	0.0102	1.000	1.889	9.864	17.996	1.084	1.232	1.042	1.270
σ_V (substitutability between capital and fuel inputs)									
Low (0.075)	0.0079	1.000	1.448	12.023	16.897	1.067	1.139	1.044	1.164
High (0.30)	0.0075	1.000	1.423	7.357	10.291	1.114	1.186	1.041	1.136
Industries compensated									
Y industry only	0.0078	1.000	1.267	9.885	12.561	1.084	1.128	1.043	1.051

In the EVN cases, compensation is provided through lump-sum tax credits.

Table 7
Efficiency "crossover points" under alternative parameter values

	Crossover point [a]	
	Technology mandate	Performance standard
Central case	67	79
β_E (end-of-pipe treatment ease)		
Very low (0.0)	n/a	7
Low (1.0)	35	54
High (4.0)	86	91
σ_K (capital adjustment costs)		
Very low (−100.0)	3	6
Low (−4.0)	35	49
High (−0.25)	76	90
σ_N (elasticity of demand for Y)		
Low (0.45)	61	79
High (1.8)	70	79
σ_U (factor-supply elasticity)		
Low (0.33)	47	63
High (1.32)	80	90
σ_V (substitutability between capital and fuel inputs)		
Low (0.075)	72	77
High (0.30)	57	83
Industries compensated		
Y industry only	54	75

[a] The value indicated is the percent abatement at which the emissions tax becomes more efficient than the policy shown when firms are compensated via a lump-sum tax credit.

the relative cost of command-and-control policies increases as end-of-pipe treatment is made more difficult. In the case without end-of-pipe treatment, where β_E equals zero, the technology mandate is no longer defined, and the fuel tax becomes equivalent to the emissions tax. For low values of β_E, the output-demand channel becomes important in reducing emissions. Since the performance standard omits this channel, its compensation-related advantage becomes small relative to its efficiency disadvantage. Hence, the critical abatement percentage beyond which the emissions tax becomes more efficient than the performance standard is lower, as indicated in Table 7. Even in the extreme case where β_E equals zero, however, the performance standard still outperforms the emissions tax for low abatement targets.

4.3.2. Capital adjustment costs

The parameter σ_K controls the adjustment costs in moving capital across sectors: higher values of σ_K imply less mobile capital. With lower capital mobility, owners of capital in the *X* or *Y* industries require greater compensation. The capital adjustment costs have relatively little effect on the intrinsic efficiency costs of abatement in the first column of Table 6, but exert a large effect on compensation-related costs, as indicated by the ratio of costs with and without EVN for the various policies. Since this parameter directly controls how much industry compensation is needed for environmental policy, it has a large impact in Table 7. The compensation-related advantage of the command-and-control policies becomes more and more important as capital adjustment costs rise. Indeed, in the high-cost case, the performance standard is more efficient than the emissions tax until 90% abatement.

4.3.3. Elasticity of demand for output from industry Y

Easier substitution between *C* and *Y* in demand increases the importance of the output-demand effect. This slightly lowers overall abatement costs and increases the relative cost of the command-and-control policies (because they make less use of the output-demand channel). The higher elasticity also increases somewhat the need for compensation, since the Y sector shrinks more under environmental policy. These two effects (higher intrinsic cost of command-and-control policies as well as greater need for compensation) compete in their impact in Table 7. They almost exactly offset each other for the performance standard with the crossover remaining at 79% abatement.

4.3.4. Factor-supply elasticity

The elasticity in the outer nest of the utility function, σ_U, controls the elasticity with which the household supplies labor and capital. Higher values for this elasticity mean that existing factor taxes lead to larger distortions in factor markets, and a higher marginal cost of public funds. A higher factor-supply elasticity raises the efficiency cost of providing compensation through lump-sum tax credits, since this compensation must be financed through higher factor taxes (which now have a higher efficiency cost). Thus, when the EVN constraint is imposed, the relative advantage of the command-and-control policies increases with the size of the factor-supply elasticity. For example, the first row of Table 6 shows that under central values for parameters the cost of the emissions tax with EVN is about 24% higher than the cost of the technology mandate with EVN (1.439/1.156). With the high factor-supply elasticity, in contrast, the emissions tax's cost is about 53% higher (1.889/1.232). Higher factor-supply elasticities likewise imply higher crossover points in Table 7.

4.3.5. Input substitution between capital and fuel

The parameter σ_V controls the ease of substitution between the intermediate input (fuel) and capital in the Y industry. A higher value for this parameter thus reduces the relative cost of policies that rely heavily on the fuel-capital substitution channel. Hence, the relative cost of the fuel tax and performance standard fall when σ_V takes a higher value. A high value for σ_V is relatively disadvantageous for the technology mandate, since this policy does not exploit the fuel-capital substitution channel. Easier fuel-capital substitution implies greater need for compensation to the upstream industry but less need for compensating the downstream industry. The change in overall compensation requirements is nearly neutral, so that the effects in Table 7 are driven primarily by the changes in relative intrinsic efficiency. With a higher substitution elasticity, the performance standard is more efficient than the emission tax over a wider range of abatement (because of the former policy's heavier reliance on input substitution), while the technology mandate becomes less efficient more quickly than the emissions tax does.

4.3.6. Industries compensated

Here we explore how results change when only the downstream industry receives compensation instead of both the upstream- and downstream industries. Narrowing the compensation net lowers the cost ratios for all policies, since less compensation is needed. The effect is particularly strong for the performance standard, which tends to hurt the upstream industry while preserving profits in the downstream industry. The results in Table 7 are as expected, with the compensation-related efficiency advantage of the command-and-control policies becoming somewhat less important when only one industry must be compensated.

5. Conclusions

The political viability of a proposed environmental policy instrument can depend on whether it is likely to avoid significant profit losses to major industrial stakeholders. We investigate the incidence of various environmental policy instruments and then explore how the aggregate costs of these instruments change with the requirement that major pollution-related industries be compensated for potential profit losses.

We interpret the simulation results in terms of two cost components: (1) an increase in intrinsic abatement cost (the cost of utilizing the channels of input substitution, end-of-pipe treatment, and output cuts in order to achieve pollution reductions), and (2) a cost directly associated with lump-sum compensation. We explore how these cost components are affected when compensation is provided either through sector-specific lump-sum tax credits or by way of sector-specific reductions in capital tax rates.

Importantly, imposing the compensation requirement has very different impacts on the costs of different policy instruments. Restoring profits through lump-sum tax credits, in particular, raises the costs of emissions taxes considerably more than it raises the costs of command-and-control policies such as performance standards and mandated technologies. This reflects the greater need for compensation under the emissions tax and the associated larger increase in the second cost component, the lump-sum compensation cost. Thus, while emissions taxes generally are more cost-effective in the absence of a compensation requirement, imposing this requirement can make the emissions tax more costly than command-and-control policies. This result occurs when a small or moderate amount of pollution abatement is required. When the abatement requirement is very extensive, the emissions tax regains its status as the most cost-effective instrument; with extensive abatement, other policies suffer significant increases in intrinsic abatement costs, which causes overall costs to exceed those of the emissions tax, despite lower compensation requirements.

The potential advantage (at low or modest levels of abatement) of command-and-control policies reflects the fact that these policies effectively include subsidy components: a performance standard is equivalent to an emissions tax and subsidy on final output, while a technology mandate is equivalent to an emissions tax and subsidy on the polluting intermediate input. The implicit subsidies limit the adverse profit impacts of these policies, thereby reducing the need for compensation. When equity value neutrality must be achieved through lump-sum tax credits, the command-and-control policies therefore have an advantage, since they require less compensation through these tax credits, which entail significant efficiency costs. The introduction of a compensation requirement can thus significantly alter the cost rankings of alternative environmental policy instruments. The extent to which the rankings are changed depends on the degree of stringency of the abatement requirement.

Some limitations in this study deserve mention. The model does not incorporate uncertainty, nor does it capture heterogeneity among producers within given industries. These elements can influence the cost rankings of policy instruments. Uncertainty is associated with costs of monitoring and enforcement, and such costs generally differ across policies. Also, as briefly mentioned above, when polluting firms exhibit heterogeneous abatement costs and regulators have imperfect information about such costs, incentive-based policies like emissions taxes and fuel taxes may have an advantage over command-and-control policies in producing a cost-effective allocation of pollution-reduction efforts across firms.

In addition, the model ignores certain complexities in the tax system that could affect relative policy costs. In particular, it ignores tax preferences toward certain forms of consumption spending, such as spending on medical care. Such tax preferences imply a narrower tax base and raise the costs of obtaining the revenues needed to finance compensation.[23] As a result, they raise the relative costs of emissions taxes and fuel taxes, which have higher compensation requirements. Moreover, the model treats all produced goods as average substitutes for leisure. To the extent that polluting goods are relatively complementary to leisure, there is a supplementary (non-environmental) efficiency case for taxing these goods more heavily than other goods (West and Williams, 2007). Such complementarities would likely reduce the intrinsic abatement costs of all abatement policies.

Finally, because the model lacks a time dimension, it is unable to explore the potential impacts of policy announcements. Such announcements offer an alternative way to reduce adverse profit impacts by enabling firms to anticipate the policies and avoid costs through early adjustments.

Notwithstanding these limitations, the present analysis reveals major ways in which the compensation requirement affects the absolute and relative costs of major environmental policy instruments.

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[23] Parry and Bento (2000) show that, to the extent that revenues from environmental taxes can be used to reduce factor taxes, the intersectoral distortions caused by tax-favored consumption spending are reduced. Correspondingly, an increase in factor taxes stemming from the need for compensation would augment intersectoral distortions relative to the no-compensation case.

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