# Mitigating the Adverse Impacts of CO2 Abatement Policies on Energy-Intensive Industries

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# Mitigating the Adverse Impacts of $CO_2$ Abatement Policies on Energy-Intensive Industries

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## 1. Introduction

In recent years economists have made considerable strides in articulating the costs of various policies to reduce U.S. emissions of carbon dioxide ($CO_2$) and other greenhouse gases. Most analyses emphasize *economy-wide* costs, giving relatively little attention to how the costs are distributed. Yet the distributional impacts of policies clearly are relevant to social welfare, and such impacts often determine political feasibility.

The distribution of the effects of environmental policies can be measured along a number of dimensions – across household income groups, across geographic regions, across generations, and across industries. The distribution across industries is very important in environmental policy debates, partly because the industries that would experience significant adverse impacts can importantly affect political outcomes. There are several potential explanations for the significant influence of industry groups in the political process. One influential explanation was articulated by Mancur Olson (1965) nearly four decades ago. Olson argued that the degree of political mobilization of a particular interest group is likely to depend on the concentration of the impact of the potential policy. When potential costs, in particular, are concentrated on relatively few economic agents (as opposed to widely dispersed among a great many), such agents have strong incentives to become involved politically. Concentrated potential costs may justify significant contributions of time and other resources to become engaged in the political process. It may be worth undertaking the fixed costs, in particular, of political involvement. If costs are sufficiently concentrated relative to benefits, the agents who would face these costs can have greater influence in the political process than those who would benefit, even if aggregate costs are smaller than aggregate benefits.

The political strength of industry stakeholders can partly explain why certain cost-effective or (arguably) efficient environmental policies have failed to achieve political success in the U.S. For $CO_2$ abatement, in particular, the most cost-effective approaches for reducing fossil-fuel-based emissions are carbon taxes and auctioned tradeable carbon permits. Under both of these policies, a significant share of the economy-wide cost would fall on major energy industries. These industries are highly mobilized politically and can block passage of such policies.

These considerations motivate examining the industry-distribution effects of environmental policies, and exploring whether policies can be designed to avoid "unacceptable" distributional effects with a minimal loss of cost-effectiveness or efficiency. The present research for the Energy Foundation employs a numerically solved general equilibrium model to assess the economy-wide costs of avoiding or mitigating adverse distributional impacts of $CO_2$ policies on important U.S. industries. The model

also helps identify how policies can be designed to keep adverse industry costs low.

Results from the model indicate that the efficiency cost of avoiding losses of profit to fossil fuel industries is relatively modest. This finding mirrors results obtained in an earlier paper (Bovenberg and Goulder [2000]). A key recognition underlying this finding is that $CO_2$ abatement policies have the potential to produce very large rents to the regulated firms. By compelling fossil fuel suppliers to restrict their outputs, the government effectively causes firms to behave like a cartel, leading to higher prices and the potential for excess profit. To the extent that the environmental policy enables the firms to retain these rents – such is the case under a $CO_2$ policy involving freely offered (or "grandfathered") tradeable permits – the firms can make considerably higher profit under regulation than in its absence. Correspondingly, the government needs to leave with firms only a fraction of these potential rents in order to preserve the profits of the regulated industries. In the present research we find that only a small fraction – around 13 percent – of the $CO_2$ permits must freely provided in order to prevent losses of profit to fossil fuel industries under a $CO_2$ abatement policy.

Government revenue has an efficiency value because it can be used to finance cuts in pre-existing distortionary taxes. Thus, the most cost-effective $CO_2$ policies are carbon taxes, and auctioned $CO_2$ permit systems in which the permits are initially auctioned (rather than freely provided). These policies collect as government revenue all of the potential rents produced by the regulations.[1] However, with only a small sacrifice of the potential revenue (by freely allocating a small percentage of the permits, introducing minor inframarginal exemptions to a carbon tax, or providing modest corporate income tax relief), profits can be preserved. And since the revenue sacrifice is small relative to the total potential rent or revenue, the efficiency cost of meeting the distributional constraints is small as well. Although the burden borne by fossil fuel producers is large enough in absolute terms to motivate substantial concern and political involvement, it nonetheless is small relative to the potential revenue that these policies could generate. Hence the efficiency cost of policies that avoid serious impacts on these industries is small relative to that of the most cost-effective policies.

Our earlier analysis focused mainly on how regulations affect the cost of "upstream" firms – fossil fuel suppliers. The present study expands on the earlier analysis, considering as well the costs imposed on"downstream" industries. We examine the cost of "widening the net" to protect profits of other, downstream industries that otherwise would face significant losses from pollution-abatement policies. How much does the efficiency cost grow as the "compensation net" becomes wider? We find that the costs of "insulating" a wider group of industries are modest as well. The reason is that much of the cost of a $CO_2$ policy is already shifted to consumers; hence the compensation required to offset the

[1]This assumes that the level of government spending is the same across the policies under comparison. If the collection of government revenue through carbon taxes or auctioned permits tended to generate higher government spending than other policies that do not yield as much revenue, then the efficiency advantage of carbon taxes or auctioned permits could disappear. This would depend on the social return to the additional government spending.

loss of profit in these industries is fairly small.

Section 2 below briefly describes the new work performed for the present study. Section 3 describes the policy experiments conducted. Section 4 provides theoretical issues underlying the impacts of the various policies on industry output and profits. Section 5 presents and interprets the results from numerical simulations. The final section offers conclusions.

## 2. New Elements in This Study

This study extended prior work with the numerical general equilibrium model in three main ways.

First, it refined and updated the data set used to perform policy experiments. The benchmark year for all policy experiments is the year 2000; thus the initial conditions for the economy are those that prevailed in that year. The new data set uses more recent information to generate the year-2000 data set than previously was available. In particular, it makes use of fairly recent input-output data from the Bureau of Economic Analysis of the Department of Commerce (www.bea.doc.gov/bea/dn2/i-o.htm). In addition, it employs very recent data on consumption expenditure, investment, and government spending from the National Income and Product Accounts (www.bea.doc.gov/bea/dn/nipaweb). New data on capital stocks were obtained from the Bureau of Economic Analysis's *Fixed Tangible Wealth in the United States*. Other data, including data on fuel prices and various tax rates, were also updated.

A second extension is to examine new and different profiles for carbon taxes (or tradeable permits prices). Prior work focused on a constant (in real terms) $25 per ton carbon tax, or on equivalent tradeable permits policies.[2] In the present study we focus on a carbon tax that rises through time, starting at $25 per ton but rising at either seven percent or nine percent per year, until the tax reaches a value of $50 per ton. From that time period on the carbon tax is held constant in real terms at $50 per ton. We also consider tradeable permits policies that lead to paths of permit prices that match the carbon tax paths just described. When permits prices match carbon tax rates in this way, a tradeable permits policy sometimes can be expected to have the same overall economic impact as a carbon tax policy. However, this is not always the case. As discussed below, a permits policy can have very different overall cost impacts if the permits are given out free.

The third extension is to consider a wider set of compensation schemes. As indicated in the

[2]The permits policies were equivalent in the sense that the number of permits issued was such as to generate a market price of $25 per ton for the permits.

introduction, prior work concentrated on "insulating" the profits of the fossil fuel producing industries. In this study we consider the added costs of widening the insulation net to protect profits of "downstream" industries, particularly those industries that use carbon-based fuels. These industries include the electric utility, petroleum refining, and metals&machinery industries.

## 3. Policies Considered

The different policy experiments are listed below. In all simulations the initial value of the carbon tax or the initial price of tradeable $CO_2$ permits is $25/ton.

### A. Carbon Tax Policies without Earmarked Compensation

A1. Constant carbon tax with revenues rebated as lump-sum transfers to households
A2. Carbon tax growing at 7% per year, revenues rebated as lump-sum transfers to households
A3. Carbon tax growing at 9% per year, revenues rebated as lump-sum transfers to households
A4. Carbon tax growing at 7% per year, revenues rebated through reductions in marginal rates of the personal income tax
A5. Carbon tax growing at 9% per year, revenues rebated through reductions in marginal rates of the personal income tax.

### B. Permits Policies

Each of these policies involves a profile of tradeable carbon permits that leads to permits prices (in dollars per ton) match those of the carbon tax in A2 (or A4) above. That is, the permits price starts at $25/ton and rises at 7% per year until it reaches a price of $50/ton, at which point the price remains constant at $50/ton.

B1. All permits auctioned
B2. Partial free allocation – enough to preserve profits in fossil fuel industries
B3. All permits freely allocated

### C. Carbon Tax Policies with Compensation

These policies all involve time-profiles of carbon taxes matching that in A2 (or A4) above.

C1. Corporate tax credits to the coal and oil&gas industries

C2. Like C1, but also including corporate tax credits to the electric utilities industry
C3. Like C2, but also including corporate tax credits to the petroleum refining industry
C4. Like C3, but also including corporate tax credits to the metals&machinery industry

## 4. Theoretical Underpinnings: Relationships between Abatement Policies and Profits

To provide background for interpreting the simulation results below, we offer here a heuristic presentation of key relationships between pollution-abatement policies and profits. This highlights the importance of whether the "potential revenues" from carbon abatement policies in fact become government revenue or instead are retained as rents by the polluting firms. The former case applies under a standard carbon tax, or under a system of tradeable permits in which the permits are auctioned. The latter case applies under a carbon tax with an inframarginal exemption, or under a tradeable permits system in which at least some of the permits are initially given out free. The major insights from this heuristic presentation are: (1) carbon-abatement policies can create "potential revenues" that are very large in relation to the loss of producer surplus that standard policies would cause, and (2) to preserve firms' profits it suffices either to allow a small fraction of the potential revenues to materialize as private rents (rather than actual government revenues), or to provide corporate tax relief that is relatively small in comparison to the "potential revenues. The numerical results in Bovenberg and Goulder (2000) and the present study support these findings. We find that the relative sacrifice of revenue is indeed quite small and that, as a result, the major fossil fuel producers can be compensated at relatively low efficiency cost.

We start by comparing two polar cases – where all potential revenues are collected by the government, and where all revenues are retained by firms. We discuss intermediate cases later.

### *a. $CO_2$ Abatement Policies with All "Potential Revenues" Collected by the Government*

The effects of these policies are suggested by Figure 1.[3] The line labeled $S_0$ in the figure is the supply curve for coal in the absence of the carbon tax. This diagram accounts for the quasi-fixed nature of capital resulting from capital adjustment costs. The supply curve $S_0$ should be regarded as an average of an infinite number of supply curves, beginning with the curve depicting the marginal cost of changes in supply in the first instant, and culminating with the marginal cost of changing supply over the

[3]This analysis abstracts from uncertainty. The presence of uncertainty introduces differences in the relative attractiveness, ex ante, of price instruments (like a carbon tax) and quantity instruments (like emissions permits). See Weitzman (1974), Stavins (1996). Recent applications to stock pollutants are provided by Hoel and Karp (1998) and Newell and Pizer (2000).

very long term, when all factors are mobile. This curve therefore indicates the average of the discounted marginal costs of expanding production, given the size of the initial capital stock. We draw the supply curve as upward sloping, in keeping with the fact that in all time frames except the very long run capital is not fully mobile and production exhibits decreasing returns in the variable factors – labor and intermediate inputs.[4]

The supply curve represents the marginal costs associated with increments in the use of variable factors to increase supply. Capital is the fixed factor underlying the upward-sloping supply curve.[5] The return to this factor is the producer surplus in the diagram. With an upward sloping supply curve, this producer surplus is positive. The existence of producer surplus does not necessarily imply supernormal profits. Indeed, in an initial long-run equilibrium, the producer surplus is just large enough to yield a normal return on the capital stock. To illustrate, at the initial equilibrium with a market price $p_0$ and aggregate quantity supplied $Q_0$, the producer surplus amounts to the triangular area bhd. On a balanced growth path, this producer surplus yields a normal (market) return on the initial capital stock so that the value of the initial capital stock equals the price of investment (and thus Tobin's $q$ is unity).

Now consider the impact of an unanticipated carbon (coal) tax. The introduction of this tax shifts the supply curve upward to $S_1$. As a direct consequence, the output price paid by coal consumers increases from $p_0$ to $p_{D1}$. However, since supply is not infinitely elastic, the suppliers of coal are not able to shift the entire burden of the tax onto demanders. Indeed, the producer price of coal declines to $p_{S1}$. This causes producer surplus to shrink to the area ***cgd***. Since this triangle is smaller than the initial producer surplus, the return on the initial capital stock (valued at the price of investment goods) falls short of the market rate of return. Hence, to satisfy the arbitrage condition, Tobin's $q$ falls below unity and the owners of the capital stock suffer a capital loss.

The situation is complicated by the fact that the carbon tax can finance reductions in other taxes, which may imply reductions in costs to firms. This will tend to offset the carbon-tax-induced losses in profits and the associated reductions in equity values. To the extent that the carbon tax revenues finance general (economy-wide) reductions in personal or corporate income taxes, the reductions in tax rates will be small and thus will exert only a small impact on costs to the fossil fuel

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[4] In the long run, in contrast, capital is fully mobile, production exhibits constant returns to scale, and the supply curve is infinitely elastic.

[5] Our focus on the use of inframarginal exemptions to accomplish distributional objectives is in the spirit of Farrow (1999), who employs a model along the lines of Bovenberg and de Mooij (1994) with one factor of production (labor). Our current analysis differs from Farrow's, however, in including capital as an imperfectly mobile factor. This enables us to consider the extent to which potential revenues are divided between lost consumer surplus ***aehb*** and lost gross producer surplus ***bhgc***, and permits us to examine the impacts on firms' profits. In the absence of imperfectly mobile capital, all potential revenues become lost consumer surplus, and none of the burden of regulation is borne by producers.

industries. If the revenues are recycled through tax cuts targeted for the fossil-fuel industries, however, the changes in marginal rates can be significant and the beneficial offsetting impact on profits and equity values may be more pronounced.

*b. $CO_2$ Abatement Policies with All "Potential Revenues" Retained by Firms*

In the diagram, the shaded rectangle $R$ (with area ***aegc***) represents the firms' payments of the carbon tax. If the government forgoes the potential tax revenue, and allows producers to retain this potential revenue as a rent,[6] the impact on profits, dividends, and equity values is fundamentally different. Consider, for example, the case in which the government restricts $CO_2$ emissions through a system of tradeable carbon permits. Since such emissions are proportional to coal combustion, the government can accomplish a given percentage reduction in emissions from coal by restricting coal output by that same percentage through the sale of a limited number of coal-supply permits. For comparability, suppose that the number of permits restricts supply to the level $Q_1$ in the figure. If the permits are auctioned competitively, then the government (ideally) collects the revenue $R$ from sale of the permits and the effects on firms are the same as under the carbon tax. In contrast, if the permits are given out free, then the area $R$ represents a rent to firms. The government-mandated restriction in output causes prices to rise, but there is no increase in costs of production (indeed, marginal production costs are lower).

As suggested by the figure, this rent can be quite large and, indeed, can imply substantial increases in profits and equity values to the regulated industries. In the figure, the post-regulation profits enjoyed by the firm are given by the sum of areas $R$ and ***cgd***. Here post-regulation profits are many times higher than the profit prior to regulation (***bhd***). Owners of industry-specific capital enjoy a capital gain as Tobin's $q$ jumps above unity. Intuitively, by restricting output, government policy allows producers as a group to exploit their market power and reap part of the original consumer surplus.

Using comparable diagrams, it is straightforward to verify that the magnitude of the profit increase under a system of freely allocated emissions permits is positively related to the price elasticity of supply and negatively related to the price elasticity of demand. It also depends on the extent of abatement (or number of permits issued relative to "business-as-usual" emissions), with such profits vanishing as the extent of abatement becomes very large.

In sum, the impact on firms' profits and equity values can be fundamentally different, depending on how much of the "potential revenue" area $R$ is retained by firms, rather than collected by the

[6] Fullerton and Metcalf (2000) emphasize the importance of rents to the overall efficiency costs of policies to reduce pollution. In the present study, we examine the extent to which policy-generated rents affect the impacts of policies on the profitability and equity values of regulated fims.

government. The impact also depends on how much of the potential revenue area $R$ lies above the initial equilibrium price. The latter, in turn, depends on the extent of abatement and on elasticities of supply and demand.

This heuristic presentation suggests, but does not confirm, that the potential revenue area $R$ will be quite large relative to the gross loss of producer surplus. The numerical simulations performed for this study provide evidence that this is indeed the case. The numerical model incorporates, in each industry, adjustment costs associated with the installation or removal of physical capital. Even with these adjustment costs, the elasticity of supply ends up being fairly high relative to the elasticity of demand. In addition, in these industries the share of total production cost represented by capital is fairly small. Together, these factors create a situation where firms can be compensated with relatively little sacrifice of potential tax revenue.

## 5. Brief Description of the Simulation Model

This section briefly describes the numerical model employed in this study, an intertemporal general equilibrium model of the U.S. economy with international trade. This model generates paths of equilibrium prices, outputs, and incomes for the U.S. economy and the "rest of the world" under specified policy scenarios. All variables are calculated at yearly intervals beginning in the benchmark year 2000 and usually extending to the year 2080.

One of the most important and distinguishing features of the model is its attention to the adjustment costs associated with the installation or reallocation of physical capital (structures and equipment). This is critical to understanding the effects of abatement policies on profits in various industries. Most CGE models ignore such adjustment costs, thus treating physical capital as perfectly mobile across industries. In such models capital immediately is reallocated across industries following a policy change in such a way as to bring marginal products of capital to equality. Profit rates are also instantly equalized across industries. This is unrealistic and prevents analysis of how environmental policies differentially affect the profits of different industries. Assessing the industry profit impacts requires a careful attention to the costs of installing or removing physical capital, and the relationship of these costs to profitability. The present model differs from most numerical general equilibrium models in attending to adjustment costs associated with changes in industry capital stocks, and in linking these costs to investment decisions and profits in a consistent way.

Other main features of the model include a fairly realistic treatment of the U.S. tax system and a detailed representation of energy production and demand. The model incorporates specific tax instruments and addresses effects of taxation along a number of important dimensions. These include

firms' investment incentives, equity values, and profits,[7] and household consumption, saving and labor supply decisions. The specification of energy supply incorporates the nonrenewable nature of crude petroleum and natural gas and the transitions from conventional to synthetic fuels.

U.S. production divides into the 13 industries indicated in Table 1. The energy industries consist of (i) coal mining ; (ii) crude petroleum and natural gas extraction; (iii) petroleum refining; (iv) synthetic fuels; (v) electric utilities; and (vi) gas utilities. The model also distinguishes the 17 consumer goods shown in the table.

## A. Producer Behavior

*General Specifications*. In each industry, a nested production structure accounts for substitution between different forms of energy as well as between energy and other inputs. Each industry produces a distinct output *(X)*, which is a function of the inputs of labor *(L)*, capital *(K)*, an energy composite *(E)* and a materials composite *(M)*, as well as the current level of investment *(I)*:

$$X = f(g(L,K), h(E,M)) - f(I/K) \cdot I \tag{1}$$

The energy composite is made up of the outputs of the six energy industries, while the materials composite consists of the outputs of the other industries:

$$E = E(\bar{x}_2, \bar{x}_3, \bar{x}_4, \bar{x}_5, \bar{x}_6, \bar{x}_7) \tag{2}$$

$$M = M(\bar{x}_1, \bar{x}_8, ..., \bar{x}_{13}) \tag{3}$$

where $\bar{x}_i$ is a composite of domestically produced and foreign made input *i*.[8] Industry indices correspond to those in Table 1.

Managers of firms choose input quantities and investment levels to maximize the value of the firm. The investment decision takes account of the adjustment (or installation) costs represented by

[7]Here the model applies the asset price approach to investment developed in Summers (1981).

[8]The functions *f, g*, and *h*, and the aggregation functions for the composites *E, M*, and $\bar{x}_i$, are CES and exhibit constant returns to scale. Consumer goods are produced by combining outputs from the 13 industries in fixed proportions.

$f(I/K)\,I$ in equation (1). $f$ is a convex function of the rate of investment, $I/K$.[9] As mentioned, attention to these adjustment costs is critical to gauging the profit-impacts of government policies.

*Special Features of the Oil-Gas and Synfuels Industries*. The production structure in the oil and gas industry is somewhat more complex than in other industries to account for the nonrenewable nature of oil and gas stocks. The production specification is:

$$X = g(Z) \cdot f[g(L,K), h(E,M)] - j(I/K) \cdot I \qquad (4)$$

where $g$ is a decreasing function of $Z$, the cumulative extraction of oil and gas up to the beginning of the current period. This captures the idea that as $Z$ rises (or, equivalently, as reserves are depleted), it becomes increasingly difficult to extract oil and gas resources, so that greater quantities of $K$, $L$, $E$, and $M$ are required to achieve any given level of extraction (output). Each oil and gas producer perfectly recognizes the impact of its current production decisions on future extraction costs.[10] Increasing production costs ultimately induce oil and gas producers to remove their capital from this industry.

The model incorporates a synthetic fuel -- shale oil -- as a backstop resource, a perfect substitute for oil and gas.[11] The technology for producing synthetic fuels on a commercial scale is assumed to become known in 2020. Thus, capital formation in the synfuels industry cannot begin until that year.

All domestic prices in the model are endogenous, except for the domestic price of oil and gas. The path of oil and gas prices follows the assumptions of the Stanford Energy Modeling Forum.[12] The supply of imported oil and gas is taken to be perfectly elastic at the world price. So long as imports are the marginal source of supply to the domestic economy, domestic producers of oil and gas receive the world price (adjusted for tariffs or taxes) for their own output. However, rising oil and gas prices stimulate investment in synfuels. Eventually, synfuels production plus domestic oil and gas supply together satisfy all of domestic demand. Synfuels then become the marginal source of supply, so that

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[9]The function $f$ represents adjustment costs per unit of investment. This function expresses the notion that installing new capital necessitates a loss of current output, as existing inputs (*K*, *L*, *E* and *M*) are diverted to install new capital.

[10]We assume representative oil and gas firms: initial resource stocks, profit-maximizing extraction levels, and resource-stock effects are identical across producers.

[11]Thus, inputs 3 (oil&gas) and 4 (synfuels) enter additively in the energy aggregation function shown in equation (2).

[12]The world price is specified to be $20 per barrel in 2000. Following Gaskins and Weyant (1996), we assume this price will rise by $5.00 (in year-2000 dollars) per decade.

the cost of synfuels production rather than the world oil price dictates the domestic price of fuels.[13]

### B. Household Behavior

Consumption, labor supply, and saving result from the decisions of a representative household maximizing its intertemporal utility, defined on leisure and overall consumption in each period. The utility function is homothetic and leisure and consumption are weakly separable (see appendix). The household faces an intertemporal budget constraint requiring that the present value of consumption not exceed potential total wealth (nonhuman wealth plus the present value of labor and transfer income). In each period, overall consumption of goods and services is allocated across the 17 specific categories of consumption goods or services shown in Table 1. Each of the 17 consumption goods or services is a composite of a domestically and foreign-produced consumption good (or service) of that type. Households substitute between domestic and foreign goods to minimize the cost of obtaining a given composite.

### C. The Government Sector

The government collects taxes, distributes transfers, and purchases goods and services (outputs of the 13 industries). The tax instruments include energy taxes, output taxes, the corporate income tax, property taxes, sales taxes, and taxes on individual labor and capital income. In the benchmark year, 2000, the government deficit amounts to approximately two percent of GDP. In the reference case (or status quo) simulation, the real deficit grows at the steady-state growth rate given by the growth of potential labor services. In the policy-change cases, we require that real government spending and the real deficit follow the same paths as in the reference case. To make the policy changes revenue-neutral, we accompany the tax rate increases that define the various policies with reductions in other taxes, either on a lump-sum basis (increased exogenous transfers) or through reductions in marginal tax rates.

### D. Foreign Trade

Except for oil and gas imports, imported intermediate and consumer goods are imperfect substitutes for their domestic counterparts.[14] Import prices are exogenous in foreign currency, but the domestic-currency price changes with variations in the exchange rate. Export demands are modeled as functions of the foreign price of U.S. exports and the level of foreign income (in foreign currency). The

[13]For details, see Goulder (1994, 1995a).

[14]Thus, we adopt the assumption of Armington (1969).

exchange rate adjusts to balance trade in every period.

### E. Equilibrium and Growth

The solution of the model is a general equilibrium in which supplies and demands balance in all markets at each period of time. The requirements of the general equilibrium are that supply equal demand for labor inputs and for all produced goods, that firms' demands for loanable funds match the aggregate supply by households, and that the government's tax revenues equal its spending less the current deficit. These conditions are met through adjustments in output prices, in the market interest rate, and in lump-sum taxes or marginal tax rates.[15]

Economic growth reflects the growth of capital stocks and of potential labor resources. The growth of capital stocks stems from endogenous saving and investment behavior. Potential labor resources are specified as increasing at an exogenous rate.

## 6. Simulation Results

This section provides and interprets results from simulations. In subsection A below, we examine the impacts of policies that do not involve any provisions to protect profits or equity values of key energy industries. The economic impacts of these policies form a reference point against which one can view the added cost of policies that mitigate the impacts on particular industries, either through free provision of carbon permits (discussed in subsection B) or by tax credits to particular industries (discussed in subsection C).

### A. Policies without Distributional Adjustments

#### 1. Lump-Sum Recycling

Under policies A1-A3, a carbon tax is introduced and the revenues are recycled to the economy as lump-sum transfers to households. Under Policy A1, the tax is held constant at $25/ton. Under policies A2 and A3, the tax rises at an annual rate of seven and nine percent, respectively, until the tax rate reaches $50/ton. This occurs after eleven years under Policy A2, and after nine years under A3.

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[15]Since agents are forward-looking, equilibrium in each period depends not only on current prices and taxes but on future magnitudes as well.

Results are summarized in Table 2. The table shows the impacts on prices, output, and after-tax profits fort years 2002 (two years after implementation) and 2025.

Under all three of these policies, the coal industry experiences the largest impact on prices and output. In this industry, prices rise by 46-55 percent by the time the policy is fully implemented (year 2002). Under policies A2 and A3, which involve rising carbon taxes, coal prices continue to increase significantly after 2002. By 2025, coal prices rise by 105.8 and 107.2 percent, respectively, under these two policies, reflecting the fact that the carbon tax has reached $50/ton by that time.

The price increases imply reductions in coal output of about 18-21 percent in the short term. When the carbon tax is kept constant at $25/ton (Policy A1), coal output falls by about 26 percent in the long run. Under the growing carbon tax (policies A2 and A3), the long-run impact on coal output is about 39 percent. These results imply a general equilibrium elasticity of demand of approximately 0.4 for coal.

In other industries the price impacts are not nearly so large. Although the carbon tax is imposed on the oil&gas industry, the resulting price increase is considerably smaller than in the coal industry, reflecting the lower carbon content (per dollar of fuel) of oil and gas as compared with coal. There are significant increases in prices and reductions in output in the petroleum refining and electric utilities industries as well, in keeping with the significant use of fossil fuels in these industries. The reductions in output are accompanied by reductions in annual after-tax profits.

The reductions in after-tax profits are associated with reductions in equity values (the present value of after-tax dividends net of new share issues). As shown in Table 3, the largest equity-value impacts are in the coal industry, where such values fall by about 43 percent under Policy A1 and 55-58 percent under policies A2 and A3. The reductions in equity values in the oil&gas, petroleum refining, and electric utilities industries are also substantial, in the range of 4-19 percent. As indicated in the table, the impacts on equity values of other industries are relatively small. Natural gas distribution enjoys an increase in equity values. This reflects the higher demands for natural gas as users of energy switch from coal, which experiences much greater price increases.

Table 4 indicates impacts on $CO_2$ emissions. Policy A1 leads to a reduction in emissions of about 11 percent relative to the business-as-usual case. Policies A2 and A3 lead to reductions of about 18 percent.[16]

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[16]This is the reduction in emissions associated with domestic consumption of fossil fuels. It accounts for the carbon content of imported fossil fuels, and excludes the carbon content of exported fossil fuels. These figures do not adjust for changes in the carbon content of imported or exported refined products. The percent change in emissions is the percentage change, between the reference case and policy-change case, in the "present value" of emissions, where the emissions stream is discounted using the after-tax interest rate. If marginal environmental damages from emissions are constant, the percentage changes in discounted emissions will be equivalent to percentage changes in damages.

Table 4 also indicates carbon tax revenues and efficiency impacts. We employ the equivalent variation measure of the efficiency impacts. This is a gross measure because the numerical model does not account for the benefits associated with the environmental improvement from reduced emissions. We refer to the negative of the equivalent variation as the gross efficiency cost or loss. As indicated in the table, Policy A1 implies a gross efficiency loss of approximately $104 per ton of emissions reduced, or 56 cents per dollar of discounted gross revenue from the carbon tax. Policies A2 and A3 lead to efficiency losses of about $127 per ton of emissions reduced, or 63 cents per dollar of discounted gross carbon tax revenue.

The earlier study, Bovenberg and Goulder (2000), focused on policies involving carbon tax rates or permits prices that remained constant at $25/ton. In contrast, with the exception of Policy A1 the simulation experiments in the present study involve carbon tax rates or permits prices that grow from $25/ton to $50/ton. Thus the policies currently examined are more stringent than those in the earlier study. This partly explains why the impacts on prices, output, as well as the overall economic costs, are significantly higher than those obtained in the previous study. Another reason for the larger impacts is that the newer data set reveals the oil&gas industry to be more carbon-intensive than indicated by the earlier data set.[17]

**2. Personal Income Tax Recycling**

Policies A4 and A5 are similar to policies A2 and A3, except that they involve recycling of the revenues through personal income tax cuts rather than via lump-sum payments. A comparison in tables 2 and 3 of columns A4 and A2, or of columns A5 and A3, indicates that the method of recycling has relatively little effect on prices, profits, or equity values of the fossil fuel industries or of the energy-intensive industries such as electric utilities and petroleum refining. However, as indicated in Table 4, the method of recycling significantly affects economy-wide efficiency costs. A comparison in Table 4 of columns A4 and A2, or columns A5 and A3, indicates that gross efficiency costs are about 34 percent lower under recycling via cuts in the marginal rate of the personal income tax than under lump-sum recycling. Under policies A4 and A5, the equivalent variation is about $85.9 and $86.7, respectively, per ton of emissions reduced. The equivalent variation per dollar of discounted carbon tax revenues is $.417 and $.421, respectively. Costs under Policy A5 are higher than under A4 because Policy A5 involves a faster increase in the carbon tax rate.

[17]Policy A1 matches a simulation considered in the earlier study. The costs under Policy A1 are in fact greater than those observed for the comparable prior simulation. One reason for this is that in our improved data set, the oil&gas industry is somewhat more carbon-intensive than in the earlier data set. The greater carbon intensity of the new data set also implies a larger impact on the overall economy. The $25/ton carbon tax now generates more revenue and implies a larger overall efficiency loss. Our current data set shows a loss of $1190 billion, as compared with $817 billion under the previous data set. However, the costs per ton of emission reduction are quite similar under the two data sets: $102.6 under the old data set, and $104.2 under the new data set.

Thus, recycling via cuts in marginal rates of the personal income tax leads to smaller efficiency losses than recycling through lump-sum transfers. Lowering the marginal rates reduces the distortionary costs of the personal income tax. This efficiency consequence has been termed the *revenue-recycling effect*. Despite the lower distortionary taxes, the carbon tax package still imposes gross efficiency costs because it tends to raise output prices and thereby reduce real returns to labor and capital. This *tax-interaction effect* tends to dominate the revenue-recycling effect. Hence the carbon tax still involves an overall economic cost (abstracting from the environmental benefits), even when the revenues are devoted to cuts in the personal income tax.[18]

## B. Permits Policies

We now consider several policies geared toward avoiding adverse impacts on the profits of selected industries. In particular, these policies are designed to achieve *equity-value neutrality*: to avoid any change in the equity values of particular industries.

We first examine how equity-value neutrality can be achieved through policies involving tradeable $CO_2$ permits. Three policies are examined in this connection. Under all of the policies, the number of permits issued is such as to yield a time-profile for the permits price that matches the carbon tax time-profile under Policy A2 (or A4): the permits price starts at $25/ton and rises at 7 percent annually until the permits price reaches $50/ton. Because these policies compel fossil fuel producers to restrict their supplies, they generate potential rents to these producers.

### 1. All Permits Auctioned

Under Policy B1, all the permits are auctioned. Revenues from the auction are recycled to the economy in the form of reductions in the marginal rate of the personal income tax. In this case, the firms do not retain any rents. The government collects as revenue from the auction what otherwise would be privately retained rent.

As indicated by tables 2 and 3, this policy's effects on output and equity values are virtually identical to those under Policy A4. Under the assumptions of the model, a permits policy involving 100

[18]This exemplifies the now-familiar result that, abstracting from the value of the environmental improvement they generate, green taxes tend to be more costly than the "ordinary" taxes they replace. Although this is the central result, the opposite outcome can arise when the pre-existing tax system is suboptimal along non-environmental dimensions (for example, involves overtaxation of capital relative to labor) and the introduction of the environmental reform helps alleviate the non-environmental inefficiency. For analysis and discussion of this issue see Bovenberg and de Mooij (1994), Parry (1995), Goulder (1995b), Bovenberg and Goulder (1997, 2001), and Parry and Bento (1999).

percent auctioning is identical to a carbon tax, provided that permits prices and tax rates have the same time-profile.[19]

## 2. Some Permits Freely Allocated

Under Policy B2, just enough permits are freely allocated to keep equity values from falling in the coal and oil&gas industries.[20] The rest are auctioned. In the column for Policy B2 in Table 3, the numbers in parentheses indicate the percentage of permits that must be freely allocated to achieve equity-value neutrality. About 8 percent permits need to be freely allocated in the coal industry, and about 14 percent must be freely allocated in the oil&gas extraction industry. Overall, 13 percent of the emissions permits need to be freely allocated.

Because relatively few permits are freely allocated, the government's sacrifice of revenue is small, relative to Policy B1. This implies relatively small loss of efficiency. As indicated in Table 4, under this policy the efficiency cost per ton of carbon abatement is $92.3. This cost is 7.4 percent higher than under the most efficient policies -- policies A4 or B1. Thus, avoiding profit losses in the coal and oil&gas industries involves a fairly modest increase in cost.

We let $a$ refer to the share of permits that must be freely allocated to preserve equity values. Section 4 indicated that $a$ is lower to the extent that the costs of regulation can be shifted forward to demanders. In terms of the analysis of Section 4, the ability to shift forward the costs of regulation means that most of the "*R* rectangle" lies above the initial price. When the initial producer surplus or cash-flow is small in relation to production cost, owners of the quasi-fixed factor (capital) can be fully compensated for the costs of regulation if they are given just a small piece of the R rectangle through the free allocation of permits.

Forward shifting is large when elasticities of supply are large and elasticities of demand are low.

---

[19]Three modeling assumptions underlying this correspondence may be noted. First, the equivalence between a carbon tax policy and an carbon-emissions permits policy would not hold in a more general model in which regulators faced uncertainty. In the presence of uncertainty, taxes and permits policies intended to lead to a given level of emissions will generally yield different aggregate emissions *ex post*. Second, we assume that a cost-effective allocation of emissions responsibilities is achieved under the permits policy. This implicitly assumes that any differences in abatement costs (associated with heterogeneity in firms' production methods) are ironed out through trades of permits. Third, our model does not distinguish new and old firms (although it does distinguish installed and newly acquired capital). The model's treatment of grandfathering is most consistent with a situation in which only established firms enjoy the freely offered emissions permits, where these permits are linked to the (exogenous) initial (or "old") capital stock.

[20]This policy is equivalent to a carbon tax (with the time-profile matching that of A-2 or A-4) with inframarginal exemptions. The value of the exemption, although tied to actual emissions in the industry (in the aggregate), would have to be exogenous from the point of view of any individual producer.

We find that the relevant elasticities of supply are fairly large, and the relevant demand elasticities are relatively low. Hence, $a$ is fairly small. In the numerical model, the elasticity of supply is determined by the share of cash-flow (payments to owners of the quasi-fixed factor, capital) in overall production cost, along with the specification of adjustment costs. We find that for the coal and oil&gas industries, cash-flow in the unregulated situation is quite small relative to production cost, which contributes to a larger supply elasticity. In addition, although adjustment costs restrict the supply elasticity in the short run, under our central values for parameters the "average" elasticity (taking into account the medium and long run) is fairly large. Indeed, the long run elasticity in the coal industry is infinite because of the assumption of constant returns to scale.[21] These conditions imply that most of the cost from abatement policies is shifted onto demand.

Table 5 provides further evidence of forward-shifting. It displays the impact of Policy A4 on gross and net output prices in the fossil fuel industries at different points in time. The price-impacts under other policies are similar. In the short run, the net-of-tax coal price falls a bit (relative to the reference-case price), but in the long run the carbon tax is fully shifted forward to users of coal. Even in the short run over 90 percent of the tax is shifted onto consumers of coal. In the oil&gas industry, the tax is entirely forward-shifted at all points in time, reflecting the fact that the U.S. is regarded as a price-taker with respect to oil&gas.[22]

While Policy B2 preserves profits in the fossil fuel industries, it does not insulate all industries from negative impacts on profits. The petroleum refining and electric utilities industries – which utilize fossil fuels (carbon) most intensively – also endure noticeable losses of profit and equity values, as indicated by tables 2 and 3. The policies examined in subsection C below aim to protect these downstream industries.

### 3. All Permits Freely Allocated

Under Policy B3, all of the permits are given out free to producers. Thus, firms are able to retain the rents corresponding to the area $R$ in Figure 1 above. The effects on prices and output are very similar to those under policies B1 and B2 as well as the carbon tax policies with comparable time-profiles for the carbon tax (namely, policies A2 and A4). However, the effects on the coal and oil&gas industries are very different. Under this policy, coal industry profits and equity values rise as a result of

[21]In the oil&gas industry, the presence of a fixed factor implies decreasing returns even in the long run.

[22]The real net-of-tax price of oil&gas is the only exogenous price in the model. This price is assumed to increase at a rate of 2.7 percent per year (in keeping with baseline assumptions employed by the Energy Modeling Forum at Stanford University). Hence the ratio of the (constant) real carbon tax rate to the (rising) net-of-tax price declines through time. This explains why, in Table 4, the percentage increase in the gross-of-tax price of oil&gas declines after 2004.

the policy change. As indicated in Table 2, profits increase by 155 percent in 2002 (three years after the policy's implementation) and by 218 percent in 2025. Equity values increase by a factor of seven (Table 3). Thus, this policy more than compensates owners of fossil fuel firms for the costs associated with having to reduce supply.

This policy is considerably more costly to the overall economy than B2. As indicated in Table 4, the cost per ton of emissions reduction is about $160. This is approximately 74 percent higher than the cost under B2 and 87 percent higher than under the most cost-effective policies (A4 and B1).

### C. Compensation through Industry-Specific Corporate Tax Credits

We now consider policies that achieve equity-value neutrality through industry-specific corporate tax credits. These policies involved a carbon tax with an identical time-profile to that under policies A2 or A4. The revenues from the carbon tax are used to finance the industry-specific corporate tax credits. Any remaining excess revenues are used to finance cuts in the marginal rate of the personal income tax (as under Policy A4). These corporate tax credits are lump-sum reductions in the tax payments that firms would otherwise have to make, rather than reductions in the marginal rate of the corporate income tax.

In the absence of compensation (policies A1-A5), the industries experiencing the largest percentage reductions in equity values are (in descending order) coal, oil&gas, electric utilities, petroleum refining, and metals&machinery. Policies C1 through C4 involve corporate tax credits to these industries. Policy C1 offers credits only to the coal and oil&gas industries. Policies C2 through C4 respectively add credits to the electric utilities, petroleum refining, and metals&machinery industries.

Introducing these tax credits has very little impact on prices or output of these industries. However, the tax credits to coal and oil&gas do involve an efficiency cost: as indicated in Table 4, the efficiency cost per ton of $CO_2$ reduction under Policy C1 is $87.2, 1.5 percent higher than the cost of the comparable policy that does not involve compensation (Policy A4). This efficiency cost reflects the fact that the tax credits absorb government revenue; hence the government must rely more heavily on distortionary taxes than in the absence of these credits.

While insulating the coal and oil&gas industries involves a noticeable efficiency cost, the added efficiency cost of widening the "insulation net" to protect additional, downstream industries is quite small. As indicated in Table 4, insulating the electric utility, petroleum refining and metals&machinery industry increases the efficiency cost by only 0.3 percent (compare efficiency costs of policies C4 and C1). This reflects the fact that much of the cost to these downstream industries is already shifted forward to consumers – for these industries, the revenue required to provide compensation is fairly small. Hence the efficiency sacrifice is small. Specifically, the present value of the tax credits required

to compensate the electric utility, petroleum refining, and metals&machinery industries is $28.08 billion. This is less than one percent of the present value of carbon tax revenues collected under Policy A4, which is $3,540 billion.

## 6. Conclusions

This study has investigated the distribution of impacts of $CO_2$ abatement policies across major U.S. industries. It has also considered the impacts under "standard" abatement policies and explores the efficiency cost of avoiding adverse impacts through the (partial) free allocation of $CO_2$ permits or through corporate tax credits.

We find that the efficiency cost of avoiding losses of profit to fossil fuel industries is relatively modest. This finding mirrors results obtained in an earlier paper (Bovenberg and Goulder [2000]). A key recognition underlying this finding is that $CO_2$ abatement policies have the potential to produce very large rents to the regulated firms. By compelling fossil fuel suppliers to restrict their outputs, the government effectively causes firms to behave like a cartel, leading to higher prices and the potential for excess profit. To the extent that the environmental policy enables the firms to retain these rents – such is the case under a $CO_2$ policy involving freely offered tradeable permits – the firms can make considerably higher profit under regulation than in its absence. Correspondingly, the government needs to leave with firms only a fraction of these potential rents in order to preserve the profits of the regulated industries. In the present research we find that only a small fraction – around 13 percent – of the $CO_2$ permits must freely provided in order to prevent losses of profit to fossil fuel industries under a $CO_2$ abatement policy.

We also examine the cost of protecting profits of other, downstream industries that otherwise would face significant losses from pollution-abatement policies. We find that the costs of insulating a wider group of industries are modest as well. The reason is that much of the cost of a $CO_2$ policy is already shifted to consumers; hence the compensation required to offset the loss of profit in these industries is fairly small.

Two caveats are in order. First, this analysis concentrates on the costs of preserving profits, ignoring labor-compensation issues. To the extent that labor is imperfectly mobile, there can be serious transition losses from policy changes, in the form of temporary unemployment. Overcoming barriers to political feasibility requires attention to these losses.

Second, it is worth emphasizing that the forces underlying the political feasibility of $CO_2$ abatement policies are complex. Protecting the profits of key energy industries may not be sufficient to

bring about political feasibility.

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Figure 1

**$CO_2$ Abatement and Profits**

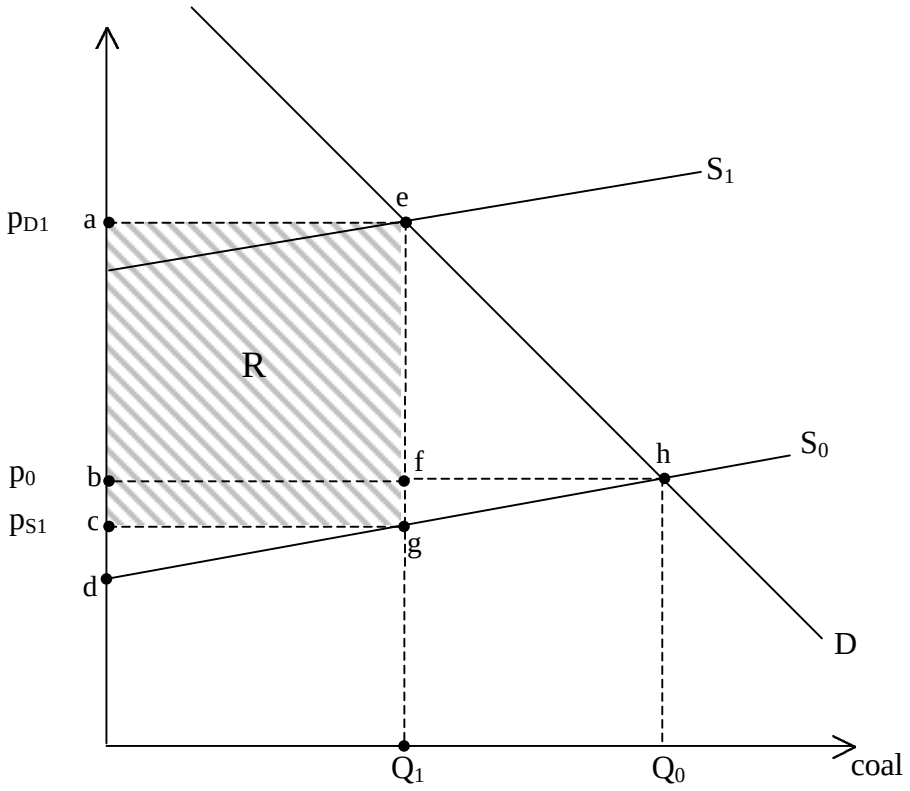

Table 1

## Industry and Consumer Goods

### Industries

| | | *Gross Output, Year 2000** | |
|---|---|---|---|
| | | Level | Percent of Total |
| 1. | Agriculture and Non-Coal Mining | 1199.9 | 7.0 |
| 2. | Coal Mining | 43.2 | 0.3 |
| 3. | Crude Petroleum and Natural Gas | 216.3 | 1.3 |
| 4. | Synthetic Fuels | 0.0 | 0.0 |
| 5. | Petroleum Refining | 298.4 | 1.7 |
| 6. | Electric Utilities | 312.2 | 1.8 |
| 7. | Gas Utilities | 184.6 | 1.1 |
| 8. | Construction | 1476.0 | 8.6 |
| 9. | Metals and Machinery | 1878.4 | 11.0 |
| 10. | Motor Vehicles | 311.5 | 1.8 |
| 11. | Miscellaneous Manufacturing | 1695.8 | 9.9 |
| 12. | Services (except housing) | 8016.4 | 46.9 |
| 13. | Housing Services | 1456.9 | 8.5 |

### Consumer Goods

1. Food
2. Alcohol
3. Tobacco
4. Utilities
5. Housing Services
6. Furnishings
7. Appliances
8. Clothing and Jewelry
9. Transportation
10. Motor Vehicles
11. Services (except financial)
12. Financial Services
13. Recreation, Reading, & Misc.
14. Nondurable, Non-Food Household Expenditure
15. Gasoline and Other Fuels
16. Education
17. Health

* in billions of year-2000 dollars

## Table 2: Industry Impacts of CO2 Abatement Policies

(percentage changes from Reference Case)

| | *Policies with No Distributional Adjustments* | | | | | *Permits Policies* | | | *Carbon Taxes Combined with Corporate Tax Credits* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Constant Carbon Tax, Lump-Sum Repl* | *Carbon Tax Growing at 7%, Lump-Sum Repl.* | *Carbon Tax Growing at 9%, Lump-Sum Repl.* | *Carbon Tax Growing at 7%, Personal Tax Repl.* | *Carbon Tax Growing at 9%, Personal Tax Repl.* | *100% Auctoning* | *Partial Free Allocation (Equity-Value Neutrality)* | *100% Free Allocation* | *Credits to Coal and Oil&Gas* | *Add Credits to Electric Utilities* | *Add Credits to Petroleum Refining* | *Add Credits to Metals&Machinery* |
| | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | C1 | C2 | C3 | C4 |
| *Gross of Tax Output Price (2002, 2025)* | | | | | | | | | | | | |
| Coal Mining | 45.8, 54.4 | 53.2, 105.8 | 55.3, 107.2 | 53.2, 105.7 | 55.3, 107.1 | 53.2, 105.7 | 53.2, 105.8 | 53.3, 105.9 | 53.2, 105.7 | 53.2, 105.7 | 53.2, 105.7 | 53.2, 105.7 |
| Oil &Gas | 15.4, 9.7 | 17.6, 19.1 | 18.3, 19.3 | 17.6, 19.1 | 18.3, 19.3 | 17.6, 19.1 | 17.6, 19.1 | 17.6, 19.1 | 17.6, 19.1 | 17.6, 19.1 | 17.6, 19.1 | 17.6, 19.1 |
| Petroleum Refining | 9.3, 6.6 | 10.7, 12.8 | 11.1, 13.0 | 10.7, 12.8 | 11.1, 12.9 | 10.7, 12.8 | 10.7, 12.8 | 10.7, 12.8 | 10.7, 12.8 | 10.7, 12.8 | 10.7, 12.8 | 10.7, 12.8 |
| Electric Utilities | 1.2, 3.7 | 1.5, 6.5 | 1.5, 6.6 | 1.7, 6.2 | 1.7, 6.3 | 1.7, 6.2 | 1.7, 6.2 | 1.6, 6.5 | 1.7, 6.2 | 1.7, 6.2 | 1.7, 6.2 | 1.7, 6.2 |
| Metal and Machinery | -0.6, -0.6 | -0.7, -1.2 | -0.7, -1.2 | -0.7, -1.2 | -0.8, -1.2 | -0.7, -1.2 | -0.7, -1.2 | -0.6, -1.1 | -0.7, -1.2 | -0.7, -1.2 | -0.7, -1.2 | -0.7, -1.2 |
| Average for Other Industries | -0.5, -0.6 | -0.6, -1.2 | -0.6, -1.3 | -0.6, -1.2 | -0.6, -1.2 | -0.6, -1.2 | -0.6, -1.2 | -0.6, -1.2 | -0.6, -1.2 | -0.6, -1.2 | -0.6, -1.2 | -0.6, -1.2 |
| *Output (2002, 2025)* | | | | | | | | | | | | |
| Coal Mining | -17.9, -26.0 | -20.3, -39.2 | -20.9, -39.5 | -20.1, -38.7 | -20.7, -39.0 | -20.1, -38.7 | -20.1, -38.7 | -20.1, -38.7 | -20.1, -38.7 | -20.1, -38.7 | -20.1, -38.7 | -20.1, -38.7 |
| Oil &Gas | -3.5, -1.8 | -5.1, -5.2 | -5.3, -5.2 | -5.5, -5.4 | -5.6, -5.4 | -5.5, -5.4 | -5.4, -5.3 | -5.1, -5.2 | -5.4, -5.4 | -5.4, -5.4 | -5.4, -5.4 | -5.4, -5.4 |
| Petroleum Refining | -6.8, -5.0 | -7.7, -9.3 | -8.0, -9.4 | -7.4, -8.7 | -7.7, -8.8 | -7.4, -8.7 | -7.5, -8.7 | -7.6, -9.2 | -7.5, -8.7 | -7.5, -8.7 | -7.5, -8.7 | -7.5, -8.7 |
| Electric Utilities | -1.9, -3.6 | -2.2, -6.3 | -2.2, -6.4 | -2.0, -5.5 | -2.1, -5.6 | -2.0, -5.5 | -2.0, -5.5 | -2.1, -6.1 | -2.0, -5.5 | -2.0, -5.5 | -2.0, -5.5 | -2.0, -5.5 |
| Metal and Machinery | -1.0, -1.1 | -1.1, -1.8 | -1.1, -1.8 | -0.7, -1.2 | -0.7, -1.2 | -0.7, -1.2 | -0.6, -1.0 | -0.6, -0.6 | -0.7, -1.2 | -0.7, -1.2 | -0.7, -1.2 | -0.7, -1.2 |
| Average for Other Industries | -0.4, -0.6 | -0.5, -1.0 | -0.5, -1.0 | -0.1, -0.4 | -0.1, -0.4 | -0.1, -0.4 | -0.1, -0.4 | -0.3, -0.7 | -0.1, -0.4 | -0.1, -0.4 | -0.1, -0.4 | -0.1, -0.4 |
| *After-Tax Profits (2002, 2025)* | | | | | | | | | | | | |
| Coal Mining | -35.6, -26.6 | -38.6, -40.5 | -39.5, -40.7 | -38.0, -40.0 | -38.9, -40.2 | -38.0, -40.0 | -23.0, -19.9 | 154.9, 217.6 | -38.0, -40.0 | -38.0, -40.0 | -38.0, -40.0 | -38.0, -40.0 |
| Oil &Gas | -4.8, -1.9 | -6.4, -5.5 | -6.5, -5.6 | -6.5, -5.5 | -6.7, -5.5 | -6.5, -5.5 | -2.8, -1.5 | 19.9, 22.3 | -6.5, -5.5 | -6.5, -5.5 | -6.5, -5.5 | -6.5, -5.5 |
| Petroleum Refining | -8.3, -5.0 | -9.2, -9.8 | -9.5, -9.9 | -8.4, -9.1 | -8.7, -9.2 | -8.4, -9.1 | -8.4, -9.1 | -8.7, -9.3 | -8.5, -9.1 | -8.4, -9.1 | -8.5, -9.1 | -8.5, -9.1 |
| Electric Utilities | -6.2, -3.7 | -6.8, -6.9 | -7.0, -6.9 | -5.4, -6.2 | -5.6, -6.2 | -5.4, -6.2 | -5.5, -6.3 | -6.0, -6.5 | -5.5, -6.2 | -5.5, -6.2 | -5.5, -6.2 | -5.5, -6.2 |
| Metal and Machinery | -2.7, -2.6 | -2.8, -4.5 | -2.8, -4.6 | -1.4, -3.5 | -1.5, -3.5 | -1.4, -3.5 | -1.3, -3.4 | -1.0, -2.3 | -1.5, -3.5 | -1.5, -3.5 | -1.5, -3.5 | -1.5, -3.5 |
| Average for Other Industries | -1.0, -1.3 | 0.0, -2.5 | -1.1, -2.6 | -0.1, -1.8 | -0.2, -1.8 | -0.1, -1.8 | -0.2, -1.8 | -0.6, -2.2 | -0.2, -1.8 | -0.2, -1.8 | -0.2, -1.8 | -0.2, -1.8 |

## Table 3: Equity Values

| | *Policies with No Distributional Adjustments* | | | | | *Permits Policies* | | | *Carbon Taxes Combined with Corporate Tax Credits* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Constant Carbon Tax, Lump-Sum Repl* | *Carbon Tax Growing at 7%, Lump-Sum Repl.* | *Carbon Tax Growing at 9%, Lump-Sum Repl.* | *Carbon Tax Growing at 7%, Personal Tax Repl.* | *Carbon Tax Growing at 9%, Personal Tax Repl.* | *100% Auctoning* | *Partial Free Allocation (Equity-Value Neutrality)* | *100% Free Allocation* | *Credits to Coal and Oil&Gas* | *Add Credits to Electric Utilities* | *Add Credits to Petroleum Refining* | *Add Credits to Metals&Machinery* |
| | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | C1 | C2 | C3 | C4 |
| *Equity Values of Firms, Year 2000 (percentage changes from reference case)* | | | | | | | | | | | | |
| Agriculture and Non-Coal Mining | -1.0 | -1.7 | -1.7 | 0.1 | 0.0 | 0.1 | 0.0 | -1.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Coal Mining | -43.2 | -55.8 | -57.6 | -54.6 | -56.4 | -54.6 | 0.0 (7.8%) | 611.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil&Gas | -9.8 | -18.5 | -18.9 | -20.0 | -20.4 | -20.0 | 0.0 (14.0%) | 124.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Petroleum Refining | -2.8 | -4.1 | -4.2 | -2.2 | -2.3 | -2.1 | -2.3 | -3.7 | -2.2 | -2.2 | 0.0 | 0.0 |
| Electric Utilities | -4.5 | -6.7 | -6.9 | -4.2 | -4.4 | -4.2 | -4.3 | -5.9 | -4.3 | 0.0 | 0.0 | 0.0 |
| Natural Gas Utilities | 1.6 | 1.9 | 2.0 | 4.3 | 4.5 | 4.3 | 4.1 | 2.6 | 4.2 | 4.2 | 4.2 | 4.2 |
| Construction | -1.8 | -2.7 | -2.8 | 1.3 | 1.4 | 1.5 | 1.0 | -1.3 | 1.3 | 1.2 | 1.3 | 1.3 |
| Metals and Machinery | -2.5 | -3.5 | -3.6 | -0.9 | -1.0 | -0.9 | -0.8 | -0.9 | -1.0 | -1.1 | -1.0 | 0.0 |
| Motor Vehicles | -0.7 | -1.2 | -1.2 | 3.3 | 3.3 | 3.3 | 3.2 | 1.5 | 3.0 | 3.0 | 3.0 | 3.1 |
| Miscellaneous Manufacturing | -2.3 | -3.4 | -3.5 | -0.9 | -1.0 | -0.8 | -0.9 | -1.6 | -1.0 | -1.0 | -1.0 | -1.0 |
| Services (except housing) | -0.7 | -1.1 | -1.2 | 1.1 | 1.1 | 1.1 | 1.0 | -0.5 | 1.0 | 1.0 | 1.0 | 1.0 |
| Housing Services | -0.5 | -1.0 | -1.0 | 0.7 | 0.7 | 0.6 | 0.4 | -0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| Total | -1.1 | -1.8 | -1.8 | -0.7 | -0.7 | -0.7 | -0.9 | -0.1 | -0.7 | -0.8 | -0.8 | -0.8 |

## Table 4: Emissions, Revenues, and Efficiency Costs

| | *Policies with No Distributional Adjustments* | | | | | *Permits Policies* | | | *Carbon Taxes Combined with Corporate Tax Credits* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Constant Carbon Tax, Lump-Sum Repl* | *Carbon Tax Growing at 7%, Lump-Sum Repl.* | *Carbon Tax Growing at 9%, Lump-Sum Repl.* | *Carbon Tax Growing at 7%, Personal Tax Repl.* | *Carbon Tax Growing at 9%, Personal Tax Repl.* | *100% Auctoning* | *Partial Free Allocation (Equity-Value Neutrality)* | *100% Free Allocation* | *Credits to Coal and Oil&Gas* | *Add Credits to Electric Utilities* | *Add Credits to Petroleum Refining* | *Add Credits to Metals&Machinery* |
| | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | C1 | C2 | C3 | C4 |
| *Emissions* | | | | | | | | | | | | |
| Absolute Change | -11.42 | -17.58 | -17.92 | -17.20 | -17.55 | -17.20 | -17.23 | -17.50 | -17.22 | -17.22 | -17.22 | -17.22 |
| Percentage Change | -14.84 | -22.85 | -23.29 | -22.35 | -22.81 | -22.36 | -22.39 | -22.74 | -22.38 | -22.38 | -22.38 | -22.38 |
| | | | | | | | | | | | | |
| *Present Value of Carbon Tax Revenues* | 2113.4 | 3553.0 | 3608.6 | 3540.2 | 3617.0 | 3541.1 | 3212.3 | 0.0 | 3540.7 | 3540.6 | 3540.6 | 3540.5 |
| | | | | | | | | | | | | |
| *Efficiency Cost* | | | | | | | | | | | | |
| Absolute | 1190.0 | 2228.0 | 2280.0 | 1478.0 | 1522.0 | 1478.0 | 1591.0 | 2810.0 | 1501.4 | 1504.8 | 1506.0 | 1506.2 |
| Per Ton of CO2 Reduction | 104.2 | 126.7 | 127.2 | 85.9 | 86.7 | 85.9 | 92.3 | 160.5 | 87.2 | 87.4 | 87.5 | 87.5 |
| Per Dollar of Carbon Tax Revenue | 0.563 | 0.630 | 0.632 | 0.417 | 0.421 | 0.417 | 0.495 | NA | 0.424 | 0.425 | 0.425 | 0.425 |

Table 5

**Price Responses under Carbon Tax***

*Ratio of Price under Policy Change to Reference-Case Price*

| | 2000 | 2001 | 2002 | 2004 | 2010 | 2025 | 2050 |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **Coal Industry** | | | | | | | |
| Output price gross of carbon tax | 1.139 | 1.321 | 1.533 | 1.632 | 1.990 | 2.054 | 2.057 |
| Output price net of carbon tax | 0.973 | 0.966 | 0.963 | 0.979 | 0.991 | 0.995 | 0.998 |
| | | | | | | | |
| **Crude Petroleum and Natural Gas Industry** | | | | | | | |
| Output price gross of carbon tax | 1.054 | 1.130 | 1.176 | 1.192 | 1.251 | 1.191 | 1.136 |
| Output price net of carbon tax | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

* Results are for Policy A4. Coal and oil&gas price responses are very similar under the other policies.