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Confronting industry-distributional concerns in U.S. climate-change policy

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Avant-propos

En introduction de sa conférence le 17 décembre 2002, Lawrence Goulder a inscrit son travail dans une perspective explicite de mobilisation des outils d'analyse économique au service de la décision publique. Cette volonté affichée d'intervenir avec pertinence au cœur du débat public exige en particulier, selon lui, d'accorder une attention permanente à l'acceptabilité des politiques publiques formulées par les économistes.

Analysant les blocages autour du débat sur la mise en œuvre de politiques de réduction des émissions de gaz à effet de serre aux Etats-Unis, il constate ainsi que les instruments les plus efficaces du point de vue traditionnel de l'économiste (taxes ou permis d'émission mis aux enchères) mobilisent contre eux des lobbies d'autant plus puissants qu'ils réunissent un petit nombre de groupes industriels, mais pour lesquels l'impact économique de la mise en œuvre de tels instruments est potentiellement très grand. Face à cette puissante mobilisation et à ses conséquences politiques avérées, il reproche aux analyses économiques publiées au cours des dernières années d'adopter une approche trop globale et de faire l'impasse sur la question essentielle de la distribution des coûts au sein de l'économie, tout particulièrement en fonction des grands secteurs d'activité.

Entre les options citées plus haut, qui minimisent les coûts globaux pour l'économie mais semblent vouées à l'échec politique, et le repli sur une allocation gratuite généralisée de permis d'émission au prix d'un surcoût économique global substantiel, il développe une panoplie d'alternatives hybrides. Ces formules alternatives sont simultanément évaluées à l'aune de leur acceptabilité politique (mesurée par leur impact sur le profit, et donc la valeur des firmes) et de leur efficacité économique (mesurée par le surcoût induit en référence aux politiques optimales), sans oublier bien évidemment leur efficacité environnementale (taux de réduction des émissions de gaz à effet de serre). Les différentes formules explorées (allocation gratuite partielle associée à différents modes de recyclage des revenus générés par les droits mis aux enchères, ou instruments fiscaux différenciés) s'appuient toutes sur le constat que la rente créée au profit de ces secteurs industriels sensibles par une allocation gratuite de droits d'émission serait systématiquement beaucoup plus importante que les pertes de profit induites par une mise aux enchères, et qu'il s'agit de compenser.

L'analyse est d'abord développée sur la base d'un modèle analytique simple, puis en recourant à un modèle d'équilibre général calculable inter-temporel de l'économie américaine. Dans ce dernier, l'introduction de coûts d'ajustement intersectoriels du capital traduit le manque de flexibilité à court terme des investissements engagés dans les secteurs de l'industrie énergétique. L'hypothèse de non-élasticité parfaite des marchés de ces firmes limite leur exposition à la concurrence et préserve la possibilité de rente. C'est précisément sur ce point que le débat s'est engagé avec les industriels français présents à la conférence, qui doutent de leur capacité effective à reporter le prix du carbone sur leurs consommateurs dans un contexte d'économie ouverte sur les marchés internationaux. L'analyse de Lawrence Goulder, qui porte sur l'hypothèse d'un marché de permis « en amont » au niveau des grandes firmes du secteur énergétique, ne peut certainement pas s'appliquer sans précaution au contexte européen. Mais d'autres travaux évoqués lors du débat (comme ceux du Cired) semblent confirmer la pertinence de cette approche appliquée à un marché de permis « en aval », au niveau des firmes émettrices de gaz à effet de serre : les firmes très intensives en énergie présenteraient en effet un niveau relativement limité d'exposition à la concurrence internationale.

A cette réserve près, les résultats exposés par Lawrence Goulder plaident fortement en faveur d'une meilleure prise en compte des potentialités ouvertes par les instruments hybrides. L'allocation par mise aux enchères de l'ensemble des droits d'émission, qui est la formule présentant le coût macroéconomique le plus faible, entraînerait selon ses estimations des pertes de valeur des firmes pouvant atteindre 20 % (industries pétrolière et gazière), voire 55 % (industrie charbonnière). Ces pertes pourraient être totalement compensées par le biais d'une allocation gratuite très partielle des droits d'émission (respectivement 14 % et 7,8 % pour les deux secteurs considérés). Ce nouveau mode d'allocation se traduirait par une perte d'efficacité limitée (moins de 10 %) et une hausse raisonnable des coûts unitaires de réduction des émissions (de 85,9 dollars à 92,3 dollars par tonne de CO_2 évitée), l'impact environnemental demeurant inchangé. Par comparaison, une allocation gratuite généralisée induirait un doublement du coût global des politiques au profit des firmes du secteur énergétique.

Les industriels présents ont également réagi sur ce point, pour évoquer les coûts internes aux entreprises induits par la mise aux enchères des droits, et que le modèle ne prend pas en compte. Les premières expériences concrètes (et en particulier la mise en œuvre du marché anglais) ont en effet révélé à quel point les entreprises n'ont qu'une connaissance très limitée de leurs courbes de coût d'abattement, bien insuffisante pour développer une stratégie cohérente d'achat de droits. Cette difficulté plaiderait en faveur d'une introduction progressive des enchères. L'expérience américaine sur les marchés de droit d'émission de SO_2 semble d'ailleurs avoir révélé que les industries concernées pouvaient accepter des efforts de réduction substantiels programmés sur le moyen terme, à condition de bénéficier d'allocations peu contraignantes en phase d'établissement du marché de droits.

Michel Colombier

Abstract

The most cost-effective policies for achieving CO_2 abatement (e.g., standard carbon taxes) are considered politically unacceptable because of distributional consequences.

This paper employs a simple analytically tractable model along with a more complex dynamic numerical general equilibrium model to assess the impacts of CO_2 policies on key energy industries. We explore how CO_2 policies can be designed to avoid adverse profit impacts in these industries, and assess the costs of meeting these potential distributional objectives.

We find that without substantial added cost to the overall economy, the government can implement carbon abatement policies that protect equity values in fossil-fuel industries. The reason is that CO_2 abatement policies have the potential to generate rents that are quite large in relation to the potential loss of profit.

By enabling firms to retain only a small fraction of these potential rents—e.g., by grandfathering a small percentage of CO_2 permits, or by exempting a small fraction of emissions from the base of a carbon tax—the government can protect firms' profits and equity values. Government revenue has an efficiency value because it can be used to

finance cuts in pre-existing distortionary taxes. Since the revenue-sacrifice involved in protecting firms' profits is small, the efficiency cost is small as well. We also find that expanding the compensation effort to include industries that significantly use carbon-based fuels does not substantially add to the overall economic cost.

Adressing industry-distributional concerns in U.S. climate-change policy

Introduction

In recent years, economists have made considerable strides in articulating the costs of 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 crucially affect political feasibility.

The distribution of the effects of CO_2-abatement 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, in particular, has been very important in policy debates, partly because affected industries appear to constitute a powerful political force.[1] The political strength of industry stakeholders helps to 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 appear to be carbon taxes and auctioned tradeable carbon permits. Under both of these policies, major energy industries would suffer substantial losses in profit. These industries are highly mobilized politically and can block passage of such policies.

These considerations motivate examining the industry-distribution effects of environmental policies. In this paper we explore alternative designs of domestic CO_2-abatement policies, showing how policies can be formulated to avoid ”unacceptable” distributional effects. In addition, we consider the effciency costs of meeting these distributional considerations: how much does preventing serious losses of profit in key industries raise the economy-wide cost of CO_2 abatement? What types of policies achieve given distributional objectives at the lowest additional cost?

We conduct this analysis beginning with a relatively simple, analytically tractable model and then employing a more complex, numerically solved intertemporal general equilibrium model of the U.S. Important distinguishing features of the numerical model are its attention to adjustment costs associated with the installation or reallocation of physical capital and its treatment of the links between these adjustment costs and industry investment and profits. These features are critical to understanding the effects of CO_2 abatement policies on industry profits. Most numerical general equilibrium models ignore such adjustment costs, thus treating physical capital as perfectly mobile across industries. In such models, after an unanticipated policy change, capital instantly moves across industries so as to equate after-tax marginal products and profit rates throughout the economy. This unrealistic treatment prevents any assessment of how environmental policies differentially affect the profits of different industries.[2]

We find that the efficiency cost of avoiding losses of profit to fossil fuel industries is relatively modest. Avoiding losses of profit in the fossil fuel industries increases the efficiency cost by about seven percent relative to the cost under the most cost-effective policies. The most cost-effective CO_2 policies —carbon taxes and CO_2 permit systems in which the permits are initially auctioned—collect the most revenue (for given amounts of abatement) and thus minimize the government's reliance on ordinary, distortionary taxes to finance the government budget. Alternative policies forego revenue, obligating the government to rely more heavily on ordinary taxes; thus they involve higher effficiency cost. We find, however, that profits in key energy industries can be preserved if the government forgoes only a small share of the potential revenue—by freely allocating only a small percentage of tradeable carbon permits (and auctioning the rest), by introducing only minor inframarginal exemptions to a carbon tax, or by providing only modest corporate income tax relief. The revenue-sacrifice (and added efficiency cost) is small because, according to our simulations, the loss of profit under a traditional carbon tax or auctioned tradeable permits is only small in relation to the potential revenues. This reflects the fact that most of the burden of CO_2 abatement policies is shifted forward to downstream users of fuels and to consumers of fuel-based products. To maintain profits, only about 10-15 percent of potential revenues from a carbon tax or from auctioned tradeable permits would need to be foregone through inframarginal tax exemptions, the free allocation of permits, or corporate tax relief.

These findings are broadly similar to results presented in our earlier paper, Bovenberg and Goulder (2001). The present paper extends the earlier work in several ways. While the earlier paper provided only a numerical analysis, the present paper employs an analytical model as well. In addition, the present paper employs an updated and expanded data set, yielding a firmer empirical basis for the simulation experiments. Finally, the present paper considers a wider range of policies. In particular, it explores how efficiency costs change as the range of industries receiving compensation expands to include several downstream industries. We find that the costs of insulating a wider group of industries are quite modest as well, again reflecting the fact that the revenue-sacrifice to compensate these industries is small in relation to the potential revenues from CO_2 abatement policies.

Section 2 below develops the analytical model. This model lays out the determinants of losses of profit to producers of fossil fuels under CO_2-abatement policies. The model also shows, for policies involving CO_2 permits, what determines the share of CO_2 permits that must be freely allocated to prevent losses of profits in these industries. The rest of the paper applies the numerical model. Section 3 describes the model. Sections 4 and 5 indicate the sources of data and the policy experiments performed, while Section 6 presents and interprets results from numerical simulations. Section 7 offers conclusions.

An analytical model

Main features

Here we provide a simple model for investigating the impact of climate-change policies on profits in an industry supplying a carbon-based fuel. A key relationship in this paper is that between ”potential revenues” from a policy initiative and the level of compensation required to prevent a loss of profit in an energy supplying industry. The analytical model indicates what share of potential revenues must be retained by firms in that industry to avoid losses of profit.

In the model, a representative household demands two goods, Y and C. Use of good Y involves polluting emissions, E, which diminish environmental quality. Utility of the household is a positive function of consumption of Y and C and a negative function of E. Labor is perfectly mobile across industries, but capital is imperfectly mobile.

Production

The Y industry produces output (energy) according to the following constant-returns-to-scale production function

$$Y = f(L,K) \qquad (1)$$

where L denotes employment, and K stands for the capital stock in the industry. Competitive maximizing behavior yields

$$P \frac{\partial f(.;\ .)}{\partial L} = W \qquad (2)$$

$$P \frac{\partial f(.;\ .)}{\partial K} = R \qquad (3)$$

where P denotes the supply price of the polluting good and R is the rental rate in the Y sector.

The supply of sector-specific capital services is formalized by the following production function:

$$g(K;\ K_R) = \bar{K} \qquad (4)$$

where $\bar{K}$ represents fixed aggregate capital supply and K_R stands for the stock of capital in the entire economy except for the Y industry. Imperfect mobility of capital (i.e. capital adjustment costs) implies that the substitution elasticities between the two types of capital K and K_R is less than infinite. The supply function can be interpreted as a multi-product firm that uses aggregate capital as an input to produce the two capital stocks K and K_R. As a result of imperfect intrasectoral capital mobility, the rental rate on capital, which can be interpreted as the sector-specific profit rate, can differ across industries. In contrast to capital, labor is perfectly mobile across industries. Hence, the wage W is the same in all industries.

Goods consumption, pollution emissions and utility

Households demand the output of the Y industry, which is an imperfect substitute for consumption commodities C produced in the rest of the economy. In particular, households maximize the following utility function

$$U = u[h(Y,C), E]$$

where $\frac{\partial h}{\partial Y}, \frac{\partial h}{\partial C}, \frac{\partial u}{\partial h} > 0, \frac{\partial u}{\partial E} < 0.$

The use of Y by the households causes pollution emissions E :

$$E = e(Y) \tag{5}$$

with $de/dY \geq 0$.

In maximizing utility, households take environmental quality as given. Maximization utility thus yields

$$\frac{\partial h}{\partial Y} \Big/ \frac{\partial h}{\partial C} = \frac{P + T}{P_c} \tag{6}$$

where P_c stands for the price of the composite good C produced in the rest of the economy and T represents the specific tax levied on the polluting commodity Y. Since the utility function is weakly separable in environmental quality, environmental quality does not directly impact household decisions.

Equilibrium

The policy change considered here is a marginal increase in the pollution tax T. Equilibrium is restored through adjustments in the price of the polluting good P and the rental rate R. Assuming that the Y industry is small compared to the rest of the economy, we treat as given the wage rate W and the commodity price P_C. The appendix provides details of the solution of the model.

As indicated in the appendix, the effect of a tax change on the output of the Y industry is:

$$y = -\left(\frac{\sigma_s \sigma_d}{\sigma_d + \sigma_s}\right) t \qquad (7)$$

where $y \equiv dY/Y$ and $t \equiv dT/P$. σ_d is defined as $\bar{\sigma}_d/(1 + T/Y)$, where $\bar{\sigma}_d$ represents the elasticity of substitution between Y and C. The supply elasticity σ_s is defined as $[\sigma_k + (1 - \alpha_k)\sigma_y] / \alpha_k$, where α_k denotes the share of capital in value added in the Y sector, σ_y represents the substitution elasticity between labor and capital in production (1), and σ_k stands for the substitution elasticity between the two types of capital in (4). Throughout we use lower case Roman letters to indicate relative changes (e.g. $y \equiv dY/Y$) unless indicated otherwise. Output of the polluting good falls substantially on account of the pollution tax if both the demand and supply elasticities are large. This is the case if capital is mobile (as indicated by large values for σ_k and thus σ_s), the immobile factor does not substantially constrain production (as indicated by small values for α_k and large values for σ_y, which imply large values for σ_s), and demand for Y is elastic (as indicated by large values for σ_d). We normalize emission units such that the elasticity of emissions with respect to output is unity. The right-hand side of (7) thus stands also for the impact on emissions.

Incidence analysis

Welfare components

The welfare impacts of a change in the pollution tax can be separated into non-environmental and environmental effects. The non-environmental effects consist of the changes in producer surplus in the Y sector and in consumer surplus, plus the change in government revenue. We express these changes relative to initial value-added in the Y sector. The relative changes in producer surplus, consumer surplus, and tax revenue are respectively given by

$$s^p = -\left(\frac{\sigma_d}{\sigma_d + \sigma_s}\right) t \tag{8}$$

$$s^c = -\left(\frac{\sigma_s}{\sigma_d + \sigma_s}\right) t \tag{9}$$

$$s^g = \left[1 - \left(\frac{\sigma_s \sigma_d}{\sigma_d + \sigma_s}\right) \bar{T}\right] t \tag{10}$$

where $\bar{T} \equiv T/P$. Recall that $\sigma_s \equiv [\sigma_k + (1 - \alpha_k)\sigma_y] / \alpha_k$ and $\sigma_d \equiv \dfrac{\bar{\sigma_d}}{(1 + \bar{T})}$.

Equation (8) implies that the Y industry bears a large part of the tax burden if consumers are price sensitive (i.e., if σ_d is large) and the immobile factor constrains production (i.e., if σ_k and σ_y are small and α_k is large so that σ_s is small). Consumers bear a larger part of the burden, the smaller the price elasticity of demand and the larger the supply elasticity in the upstream industry (i.e. the more mobile capital is or the less important capital is in production).

Relationships between potential revenues and producer surplus

Equity value neutrality

We are especially interested in how producer surplus is altered when some of the potential tax revenues either are left with producers (through free lump-sum allocation of permits) or are explicitly given to producers as lump-sum payments. Let s^p_γ represent the change in producer surplus associated with a given policy change when the fraction γ of potential revenues is left with producers. Thus

$$s^p_\gamma = \gamma \cdot s^g + s^p$$

where s^p denotes producer surplus in the absence of any compensation (given by (8)). Substituting (8) and (10) into this expression to eliminate s^p and s^g, we find

$$s^p_\gamma = \gamma \left[1 - \left(\frac{\sigma_s \sigma_d}{\sigma_d + \sigma_s}\right) \bar{T}\right] - \left(\frac{\sigma_d}{\sigma_d + \sigma_s}\right) \qquad (11)$$

Define γ_n as the share of potential revenues that must be left with the firm to assure *equity value neutrality*, that is, to prevent any reduction of producer surplus as a result of the policy change (i.e. $s^p_{\gamma_n} = 0$)[3]. The share γ_n that ensures equity value neutrality for this sector must satisfy the following equation

$$\gamma_n \left[1 - \left(\frac{\sigma_s \sigma_d}{\sigma_d + \sigma_s}\right) \bar{T}\right] = \left(\frac{\sigma_d}{\sigma_d + \sigma_s}\right) \qquad (12)$$

γ_n can be interpreted as the share of additional pollution permits that must be distributed free (and lump sum) to the industry (i.e. the share that is not being auctioned). It tends to be small if the demand elasticity is small or the supply elasticity $\sigma_s \equiv [\sigma_k + (1 - \alpha_k)\sigma_y] / \alpha_k$ is large. It also tends to be small when $\bar{T}$ is small, that is, when environmental policy is not ambitious.

The share γ_n can exceed unity if initial environmental policy is ambitious (i.e. $\bar{T}$ is large) and the supply elasticity is small compared to the demand elasticities (i.e. σ_s/σ_d is small so that the right-hand side of (12) is close to unity). Under these circumstances, a further increment in environmental protection involves relatively large additional costs. At the same time, the producers would bear a large share of these costs, given the relatively small supply elasticities. Even if all the permits were distributed freely to firms (i.e., if γ_n were unity), firms would not enjoy enough rent to offset the marginal costs of environmental policy. Accordingly, to avoid reducing profits in the *Y* industry, the government would have to freely allocate all the original emissions permits and buy back some of these permits as well (or provide further compensation some other way).

Full revenue recycling

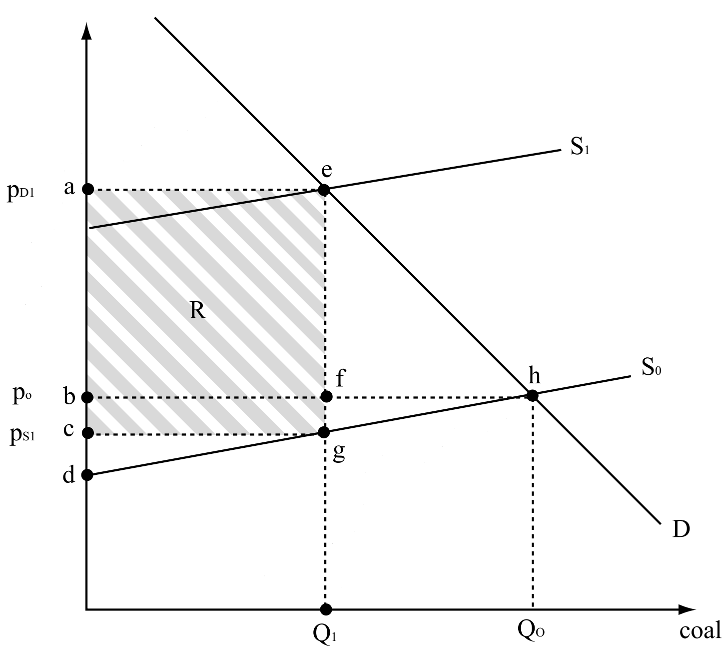
Let s^p_1 represent the change in producer surplus when all potential tax revenues are left with the *Y* industry, that is, when γ is 1. In this case, the change in producer surplus amounts to

$$ps_1 = \left(\frac{\sigma_s}{\sigma_d + \sigma_s}\right)[1 - \bar{T}\sigma_d] \qquad (13)$$

In this circumstance, what otherwise would be environmental tax revenue (or revenue from auctioned permits) is retained as rents by private firms. Equation (13) indicates that an industry may actually enjoy an increase in producer surplus in this case. When γ is 1, the environmental tax (or restricted supply of emissions permits) compels firms to reduce their output, which drives up the output price and redistributes rents away from consumers to producers. In this case, the environmental policy induces firms to behave much like a cartel, restricting output and enjoying monopoly rents.[4]

These ideas are expressed heuristically in Figure 1. The line labeled S_0 in the figure is the supply curve for coal in the absence of a carbon-abatement policy. This diagram accounts for the quasi-fixed nature of capital resulting from capital adjustment costs.[5] Capital is the fixed factor

Figure 1. Abatement and profits



underlying the upward-sloping supply curve. The return to this factor is the producer surplus in the diagram. With an upward sloping supply curve, this producer surplus is positive.

The introduction of a carbon (here coal) tax shifts the supply curve upward to S_1. 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}. Under the most cost-effective abatement policies —a standard carbon tax or a system of auctioned tradeable permits— the government collects revenues represented by the rectangle *R*. The producer surplus loss is the area **bhgc** in the diagram —the difference between original producer surplus **bhd** and the post-policy–producer surplus **cgd**. If, in contrast, the government foregoes some of the potential revenues, some of the rectangle *R* is retained by producers. In the situation where the government foregoes all of the potential revenues, the change in producer surplus is **aefb** minus **fhg**, equal to the policy-induced rent *R* minus the gross loss of producer surplus **bhgc**. As drawn, the diagram indicates that in this circumstance producer surplus would increase. In keeping with the results derived above, the diagram suggests that the share of potential revenues required for equity neutrality falls as supply becomes more elastic and as demand becomes less elastic.

The simulation model

This section briefly describes the numerical model employed in this study. In contrast with the analytical model of Section 2, the numerical model is dynamic (encompassing many time periods) and general equilibrium in nature. 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.

As mentioned in the introduction, a key feature of the model is its attention to the adjustment costs associated with the installation or reallocation of physical capital (structures and equipment). 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 features 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'

Table 1. Industry and consumer goods

		*Gross Output, Year 2000**	
	Industries	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

* in billions of year-2000 dollars

Consumer Goods

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

investment incentives, equity values and profits, 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; (vi) gas utilities. The model also distinguishes the 17 consumer goods shown in the table.

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 composit (E) and a materials composite (M), as well as the current level of investment (I):

$$X = f[g(L, K), h(E, M) - \phi(I/K) \cdot I \qquad (14)$$

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:

$$E = E(\bar{x}_2, \bar{x}_3 + \bar{x}_4, \bar{x}_5, \bar{x}_6, \bar{x}_7) \qquad (15)$$

$$M = M(\bar{x}_1, \bar{x}_8, \ldots, \bar{x}_{13}) \qquad (16)$$

where x_i is a composite of domestically produced and foreign-made input i.[6] 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 $\phi(I/K) \cdot I$ in equation (14) ϕ is a convex function of the rate of investment, I/K.[7] 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:

$$X = \theta(Z) \cdot f[g(L,K),\ h(E,M)] - \phi(I/K) \cdot I \qquad (17)$$

where θ 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.[8] 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.[9] 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.[10] 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 the cost of synfuels production rather than the world oil price dictates the domestic price of fuels.[11]

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.

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.

Foreign trade

Except for oil and gas imports, imported intermediate and consumer goods are imperfect substitutes for their domestic counterparts.[12] 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 exchange rate adjusts to balance trade in every period.

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 lumpsum taxes or marginal tax rates.

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.

Data

For this study we 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/io.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.

Policy experiments

Below we list the three types of policies considered. 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. 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 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

Each of these policies involves 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

Simulation results

This section provides and interprets results from simulations. In the first subsection 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 2) or by tax credits to particular industries (discussed in subsection 3).

Policies without distributional adjustments

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.

Results are summarized in Table 2, page 28. The table shows the impacts on prices, output and after-tax profits for 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

Table 2. Industry impacts of CO_2 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% Auctioning*	*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

two policies, reflecting the fact that the carbon tax has reached \$50/ton by that time. These 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, page 30, 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, page 32, 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.

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

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% Auctioning*	*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

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.

Our earlier study, Bovenberg and Goulder (2001), 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.

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

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

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.

Tax 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.

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.

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

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. 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 2 indicated that γ_n is lower to the extent that the costs of regulation can be shifted forward to demanders. In terms of the analysis of Section 2, 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. We find that the relevant elasticities of supply are fairly large, and the relevant demand elasticities are relatively low. Hence, γ_n 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. 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

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

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.

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 below aim to protect these downstream industries.

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, page 19. 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 the policy change. As indicated in Table 2, page 28, 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, page 30). 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).

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, page 32, 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.

Conclusion

This study has investigated the distribution of impacts of CO_2 abatement policies across major U.S. industries. We analyzed the impacts under "standard" abatement policies and explored 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 major suppliers and users of carbon-based fuels is relatively modest. Neutralizing the adverse impacts on profits of the fossil-fuel supplying industries, in particular, raises efficiency costs by only about seven percent relative to those under the most cost-effective policies. 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. Our numerical results indicate that the government needs to leave with firms only a fraction of these potential rents in order to preserve the profits of the regulated industries. We find that only a small fraction—around 13 percent—of the CO_2 permits must be 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 further downstream to other industrial users, or to households that consume energy-based products; hence the compensation required to offset the loss of profit in these industries is fairly small.

Some 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.

Appendix

This appendix derives the equations employed in the main text.

Supply

Log-linearizing the production function (1), we find

$$y = k + (1 - \alpha_k)(1 - k) \qquad (18)$$

As before, small Roman letters denote relative changes (unless indicated otherwise) of the variables denoted by the corresponding capital letters. Greek letters represent elasticities and shares in the initial equilibrium. In particular, $\alpha_k \equiv RK/(RK + WL)$ stands for the share of capital in value added of the Y industry in the initial equilibrium.

With a constant-returns-to-scale production function (1), the relative change in the output price is a weighted average of the relative changes in the input prices (note that wages do not change)

$$p = \alpha_k r \qquad (19)$$

Capital supply is given by

$$k = \sigma_k r \qquad (20)$$

where σ_k stands for the substitution elasticity between the industry-specific capital services in the Y industry and the capital services in the rest of the economy.

Using (2) and (3) to eliminate P and log-linearizing the results, we arrive at

$$l - k = \sigma_y r \qquad (21)$$

where σ_y stands for the substitution elasticity between the two production factors in the Y industry.

Substituting (20), (21) and (19) into (18) to eliminate k, $(l - k)$, and r, we write the supply of the final good in terms of its price and the demand price of the intermediate good

$$y = \sigma_s p \qquad (22)$$

where $\sigma_s \equiv [\sigma_k + (1 - \alpha_k)\sigma_y] / \alpha_k$ denotes the supply elasticity. This elasticity becomes infinite if capital (i.e. the 'fixed' factor) does not play a role in production (i.e. $\alpha_k = 0$), if capital is a perfect substitute for capital in the rest of the economy (i.e. $\sigma_k \Rightarrow \infty$ so that adjustment costs are absent), or if mobile labor is a perfect substitute for the imperfectly mobile factor (i.e. capital) (i.e. $\sigma_y \Rightarrow \infty$). In all these cases, the immobile factor does not constrain production of the final good.

Demand

Log-linearization of (6) yields the demand function

$$y = - \sigma_d(p + t) \qquad (23)$$

Here $t \equiv dT/P$ and $\sigma_d \equiv \bar{\sigma}_d/(1 + \frac{T}{P})$ where $\bar{\sigma}_d$ represents the substitution elasticity between the polluting commodity Y and other consumption goods C in the household utility function $u(\, , \,)$.

Equilibrium

The demand for the polluting good is given by (23). The supply is given by (22). Setting demand equal to supply, we arrive at

$$p = - \left(\frac{\sigma_d}{\sigma_d + \sigma_s}\right) t \qquad (24)$$

and

$$p + t \left(\frac{\sigma_s}{\sigma_d + \sigma_s}\right) t \qquad (25)$$

Demand bears most of the emission tax burden (i.e. the demand price rises substantially), as indicated by the sign of $p + t$, while the supply price P does not decline much, if demand is inelastic compared to supply (i.e. if σ_d is small compared to σ_s).

The effect on the output of the upstream sector is given by (substitute (25) into (23) to eliminate p) (7).

$$y = -\left(\frac{\sigma_s \sigma_d}{\sigma_d + \sigma_s}\right) t \qquad (26)$$

Welfare

The burden of the pollution tax is distributed over the producer surplus in Y sector, S^p, and the non-environmental consumer surplus, S^c. We express the changes in these three components of non-environmental welfare in terms of the initial value added in the upstream sector PY

$$s^p \equiv \frac{dS^p}{PY} = p = \alpha_k r \qquad (27)$$

$$s^c \equiv \frac{dS^c}{PY} = -p - t \qquad (28)$$

The government collects tax revenues S^g. The change in potential tax revenues measured in terms of initial value added in the upstream sector is given by

$$s^g \equiv \frac{d(S^g)}{PY} = t + \bar{T} y \qquad (29)$$

where $\bar{T} \equiv T/P$. The change in overall non-environmental welfare, S, is thus given by

$$s \equiv \frac{dS}{PY} = s^p + s^c + s^g = \bar{T} y$$

The change in overall welfare $\bar{s}$ includes the impacts on non-environmental and environmental welfare:

$$\bar{s} \equiv s - \xi y = (\bar{T} - \xi) y$$

where $\xi \equiv (\frac{\partial u}{\partial E}\frac{dE}{dY})/P$ denotes the marginal environmental damage of output (in terms of money).[13] Adding the environmental component to the non-environmental consumer surplus, we find for the change in the overall consumer surplus $\bar{s}^c$

$$\bar{s}^c \equiv -p - t - \xi y$$

In order to find the reduced forms for the three components of non-environmental welfare (i.e. (27), (28) and (29)), we substitute (24) and (7) into the equations for the three components of non-environmental welfare to arrive at (8), (9) and (10) while overall non-environmental welfare is given by:[14]

$$s = \bar{T}y = -\left[\bar{T}\left(\frac{\sigma_s\sigma_d}{\sigma_d+\sigma_s}\right)\right]t$$

Notes

1. 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), who argued that the degree of political mobilization of interest groups 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, such agents have greater incentives to incur the significant sacrifices of time and other resources required for engagement in the political process. If costs are sufficiently concentrated relative to benefits, the agents who would face these costs can exert greater influence on the political process than those who would enjoy the widely dispersed benefits, even if aggregate benefits exceed aggregate costs.

2. As an alternative, some models examine impacts on output as a proxy for impacts on profits. However, as shown below, changes in output are not reliable indicators of changes in profitability.

3. Equity value neutrality ensures that consumers pay for the cleaner environment. In this model, consumers enjoy all of the benefits from a cleaner environment —there are no direct benefits to producers. Under these conditions, equity value neutrality makes the pollution tax a benefit tax.

4. Thus, there is a close link between environmental policy and antitrust policy. As Buchanan showed, environmental policy and anticompetitive behavior are substitutes: the implicit tax imposed by a monopoly acts like an implicit environmental tax, thereby reducing the need for explicit pollution taxes.

5. The supply curve S_0 is upward sloping in the static analytical model because of increasing marginal adjustment costs. A fully dynamic model would imply different supply curves for the short, medium, and long run. One can regard the supply curve in Figure 1 as an average of an infinite number of supply curves, beginning with the curve depict-

ing the marginal cost of changes in supply in the first instant, and culminating with the marginal cost of changing supply over the very long term, when all factors are mobile. The curve therefore indicates the average of the discounted marginal costs of expanding production, given the size of the initial capital stock.

6. 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.

7. The function ϕ 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.

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

9. Thus, inputs 3 (oil&gas) and 4 (synfuels) enter additively in the energy aggregation function shown in equation (15).

10. 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.

11. For details, see Goulder (1994, 1995a).

12. Thus, we adopt the assumption of Armington (1969).

13. This assumes that only the environmental benefits accrue to consumers only. This assumption makes sense if environmental benefits are a public good and are thus distributed uniformly over the entire population. Since the upstream industry is small compared to the rest of the economy, almost all environmental benefits accrue to consumers rather than the owners of the polluting industries. Hence, to ensure that a pollution tax is Pareto-improving, the consumers need to pay for the improvement in environmental quality. This ensures that the pollution tax becomes a benefit tax.

14. This first-order welfare effect is zero if we start from an initial equilibrium without a pollution tax.

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