Are Emissions Permits Regressive?

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Abstract

Grandfathered emissions permits redistribute income to wealthy households by creating firm rents that ultimately accrue to shareholders. Consequently, they can be highly regressive, even if the poor do not have large budget shares for polluting goods. Using an analytical model, this paper estimates the burden borne by different income groups when emissions permits are used to control power plant emissions of carbon, SO_2, and NO_x. We also compare the burden borne by poor households under permits with that under emissions taxes, performance standards, technology mandates, and input taxes. And we show how the social costs of policies differ from efficiency costs when society has aversion to inequality.

Key Words: equity effects; pollution controls; emissions permits; social welfare function

JEL Classification Numbers: Q28, H22, H23

Contents

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Introduction

Economists have long advocated the use of market-based policies to achieve environmental objectives—namely emissions taxes and tradable emissions permits—as, unlike "command and control" policies, they allow firms the flexibility to reduce pollution at lowest cost. Indeed the superiority of market-based approaches has been recognized in a number of recent policy initiatives and proposals. At the national level, tradable emissions permits have been implemented for power plant emissions of sulfur dioxide (SO_2), and at the regional level for nitrogen oxides (NO_x) in the Los Angeles Basin and for a group of states in the Northeast. Proposals to implement tradable permits at the national level for mercury and NO_x, and to tighten the program for SO_2, are currently being debated. Moreover, the tradable permits approach pioneered by the US is now receiving a great deal of attention throughout the world as a possible tool in managing greenhouse gas emissions.

To date regulators in the US have given out emissions permits for free by "grandfathering" them; there has been practically no use of emissions taxes or auctioned permits. However recent literature exploring the interactions between environmental policies and the broader fiscal system has shown that there is an important efficiency advantage to using emissions taxes/auctioned permits over grandfathered permits. By increasing firm production costs and product prices environmental policies reduce the real household wage and can have adverse effects on labor supply in the same way that a direct tax does. The reduction in labor supply leads to a welfare loss in the tax-distorted labor market that can be substantial in magnitude relative to the partial equilibrium welfare effects of environmental policies. Unlike under grandfathered permits, much of this additional cost can be offset, or perhaps more than offset, under emissions taxes/auctioned permits, if the revenues from these policies are used to reduce distortionary taxes.[1]

[1] See for example Goulder et al. (1997), Parry et al. (1999) and Parry and Bento (2000).

This paper focuses on another disadvantage from using grandfathered permits instead of auctioned permits/emissions taxes that has to do with their potentially adverse effect on the distribution of household income. Grandfathered permits enact an income transfer towards higher-income groups at the expense of other households. This is because they create windfall gains for shareholders, who tend to be relatively wealthy; firms receive emissions permits for free and the market value of the permits is reflected in higher firm equity values. There is no windfall gain to wealthy households under other market-based or command and control approaches. Under auctioned permits, emissions taxes and input taxes, instead the government obtains revenues that can be recycled in broad tax reductions, or reductions that favor the poor. And under command and control policies, such as technology mandates, there is no binding quota on economy-wide emissions; hence no quota rents are created.[2]

A number of papers provide a positive analysis of the distributional effects of environmental policies, though almost all focus on either pollution, energy, and transportation taxes, or the existing structure of predominantly command and control environmental regulations. Broadly speaking, this literature finds that these policies tend to be regressive, as low-income households spend a larger share of their income than higher-income groups on products whose prices rise as a result of the policies. However the degree of regressivity is significantly diminished when measures of lifetime household income, as opposed to annual income, are used.[3]

To our knowledge there is only one prior study that has examined the household distribution effects of emissions permits. This is a paper by Dinan and Rogers (2002) that looks at the effects of a 15% reduction in US carbon emissions, under different mechanisms for allocating emissions permits. They estimate that households in the lowest income quintile would

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[2] The government does indirectly obtain some revenues under grandfathered permits through the taxation of permit rents. This effect is taken into account in our analysis.

[3] See for example Metcalf (1999) on carbon taxes; Poterba (1991a) and Casler and Rafiqui (1993) on fuel taxes; Poterba (1991b) on a broad range of energy taxes; Walls and Hansen (1999), West (2001), and Mayeres (2001) on transportation taxes; and Gianessi et al. (1979), Freeman (1979) and Robison (1985) on command and control policies.

The distributional effects of environmental policies can also be viewed in terms of impacts on different regions of the country, on firms versus consumers, and on different industries. For some discussion of these issues see Pizer and Sanchirico (2001), Bovenberg and Goulder (2001), and Morgenstern et al. (2002) respectively.

be worse off on average by around \$500 per year under grandfathered permits; households in the top income quintile would be better off by around \$1,000, as the increased value of their stockholdings more than compensate them for the increase in energy prices (see their Table 6, top two rows). If instead the permits were auctioned with revenues returned in equal lump-sum rebates for all households, Dinan and Rogers estimate that low-income households would on net be better off by around \$300 while high-income households would be worse off by around \$1,700.[4]

This paper furthers the analysis of the distributional effects of emissions permits in a number of respects. First, by considering a broader range of pollutants and parameter scenarios. We develop a generic analytical model subsequently calibrated to provide rough calculations of the distributional effects of using grandfathered permits to control power plant emissions of SO_2, carbon and NO_x. We illustrate results over a wide range of scenarios by varying the amount of abatement, budget shares across income groups, the portion of rents obtained by the government through profits taxation, etc.[5]

Second, we compare the burden on low-income households under emissions permits with their burden under a range of other policy instruments. These include emissions taxes or fully auctioned emissions permits, performance standards, technology mandates, and dirty input taxes.[6] Third, we provide some normative analysis by illustrating how the social costs of grandfathered permits and other emissions control policies differ from their pure efficiency costs when the social welfare function exhibits varying degrees of aversion to inequality.

We summarize some of the main results as follows. We find that using grandfathered emissions permits to reduce carbon emissions from electricity by 10%, and NO_x emissions by 30%, can be highly regressive; the top income quintile is made better off while the bottom

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[4] On the other hand they find auctioned carbon permits to be regressive if revenues are used to cut payroll taxes, and highly regressive if they are used to cut corporate taxes.

[5] Another virtue of our approach (compared with Dinan and Rogers 2002) is that we derive explicit formulas for the distributional burden of environmental policies, which makes the underlying parameters very transparent. On the other hand, the computations in Dinan and Rogers are a lot more sophisticated than ours.

[6] The efficiency properties of these instruments have been compared in prior work (e.g., Spulber 1985, Goulder et al. 1999), but not their equity effects.

income quintile is much worse off. The cap on SO_2 emissions mandated by the 1990 Clean Air Act Amendments—which has reduced emissions by roughly 45%—is also regressive, but less so. This underscores an important point: the magnitude of permit rent relative to pure abatement costs, and hence the scope for perverse income redistribution, diminishes at more substantial levels of emissions control. We also find that the burden imposed on low-income households can be lower under other policies—particularly emissions taxes, but also performance standards, technology mandates, and input taxes—than under grandfathered permits, as these other policies do not enact a transfer to wealthy shareholders. The overall social costs of grandfathered permits may also be significantly larger than other policies, when the social welfare function exhibits aversion to income inequality.

These results should be viewed with caution, as there are a number of caveats to the analysis. One is that we focus on current policies for SO_2 and NO_x—emissions controls proposed in various multi-pollutant bills before Congress are ultimately far more stringent and, as already emphasized, distributional effects are less pronounced at higher levels of abatement.[7] Another is that we assume competitive production; this may ultimately be reasonable if the momentum for electricity restructuring is maintained, but it is unrealistic for power generation at present. In states that still regulate electricity prices the opportunity cost of grandfathered emissions permits is not passed on in higher product prices (Burtraw et al. 2001). And for many utilities marginal generation is from gas-fired plants rather than coal fired plants; under these conditions some of the abatement costs at coal-fired plants may come at the expense of infra-marginal producer rents rather than being fully reflected in higher product prices. It would be useful to model these special features of the electricity market in future work. Other caveats are that we do not integrate environmental benefits and that the use of social welfare weights is highly controversial. Nonetheless, the paper does provide a transparent, albeit preliminary, framework for understanding the household distribution effects of emissions permits and other emissions control instruments.

The rest of the paper is organized as follows. The next section presents the analytical model and derives formulas for the burden borne by income groups under different emissions

[7] See www.rff.org/multipollutant for a discussion of air pollution bills. One reason for looking at existing emissions controls is that our abatement cost functions are highly simplified and might be misleading for abatement levels that differ greatly from current levels.

control policies. Section 3 calibrates the model to SO_2, carbon and NO_x. Section 4 presents the main quantitative results. Section 5 discusses social costs when society has aversion to inequality. Section 6 offers conclusions and discusses limitations.

1. The Model

1.1. Assumptions

1.1.1 Households.

Consider a static economy with households divided into five groups according to income: group 1 is the lowest income quintile, group 2 the next lowest, etc. Each group has N households, so the total number of households is $5N$. All households purchase two consumption goods and work a fixed amount of time. The utility function of the representative household of group i is:

(1) $$U_i(C_i, D_i)$$

D_i is consumption of a dirty good (e.g., electricity, chemical or metal products) whose production causes pollution emissions and C_i is aggregate consumption of all other (clean) goods. Utility is defined gross of environmental quality. Aggregate consumption of the goods is:

(2) $$C = \Sigma_{i=1}^{5N} C_i \, ; D = \Sigma_{i=1}^{5N} D_i$$

The wage rate of representative household i, denoted w_i, is exogenous.[8] We do not explicitly model pre-existing labor taxes, though these are implicitly taken into account in our measure of the income distribution in Section 3. Disposable income, after pollution regulation, is $I_i = w_i + \pi_i + G_i$. Here π_i is profit income, which is positive when pollution is controlled by grandfathered emissions permits, and depends on household i's stock holdings in the dirty good

[8] w_i can be thought of as the household's effective labor units.

industry. G_i is a cash transfer to household i from the recycling of any government revenues obtained from environmental policies. The household budget constraint is:

(3) $C_i + pD_i = I_i$

p is the price of the dirty good and the price of the clean good is normalized to unity.

Households choose C_i and D_i to maximize utility (1) subject to the budget constraint (3). Approximating by assuming demand for the dirty good is linear over the relevant range the individual demand functions can be expressed:[9]

(4) $D_i \approx \{1 + \eta_i (p - p_0) / p_0\} D_i^0 ; \eta_i = \frac{dD_i}{dp} \frac{p_0}{D_i^0} ; D_i^0 = s_i I_i$

Superscript 0 denotes a value in the initial or pre-regulation equilibrium, s_i is i's budget share for the dirty good and η_i is i's price elasticity of demand for the dirty good (s_i and η_i are evaluated at pre-regulation prices).

1.1.2 Firms.

Firms are homogeneous and competitive and they use labor to produce the two consumption goods with linear technology.

Aggregate emissions from production of the dirty good are:

(5) $E = eD$

where e is emissions per unit of output. Firms can reduce e through end-of-pipe abatement activity (e.g., post-combustion scrubbers for SO_2 and NO_x emissions) or substituting cleaner inputs in production (e.g. substituting low-sulfur coal for high-sulfur coal to reduce SO_2, substituting gas generation for coal generation to reduce carbon). We distinguish these two options later but for now we denote the minimized cost for reducing emissions per unit of D by:

[9] This approximation is reasonable for our purposes: the proportionate change in dirty good production in response to environmental regulations in our quantitative analysis is small.

(6) $$c(a) = \frac{\gamma a^{\theta}}{\theta}$$

where a is emissions abatement per unit. $a = e_0 - e$ where e_0 is baseline emissions with no abatement. $\gamma > 0$ and $\theta > 1$ are parameters and $c(.)$ is a convex function.[10]

1.2. Emissions Permits

Suppose that the government imposes a system of (tradable) emissions permits and that the resulting equilibrium permit price is τ; thus, permit rents are τE. We assume that the government obtains fraction λ of these rents, through taxing profit income, or possibly auctioning a portion of the permits. $\lambda = 0$ corresponds to a fully grandfathered policy with no taxation of rents; $\lambda = 1$ corresponds to a fully auctioned permit program, an emissions tax, or 100% profit taxation. Government revenue, R, is:

(7) $$R = \lambda \tau E$$

We consider two possibilities for the recycling of government revenues:

(8) $$G_i^{PROP} = \frac{R}{N} \frac{I_i^0}{\Sigma_{i=1}^5 I_i^0}; G_i^{LST} = \frac{R}{5N}$$

$G_i = G_i^{PROP}$ is a distributionally neutral case in which government revenues are returned to household i in proportion to the household's income as a share of total income. $G_i = G_i^{LST}$ is a progressive case where revenues are divided in equal lump sum transfers across all $5N$ households.[11]

[10] Implicitly, firms also produce dirty and clean intermediate goods used in the production of D. Explicitly modeling intermediate goods does not affect the results, so long as they are produced with constant returns.

[11] The use of revenues from environmental policies to reduce income taxes has been discussed extensively in the recent "double dividend" literature (e.g., Goulder 1995, Oates 1995). Lump-sum rebates have been proposed in the context of carbon permits (e.g., Kopp et al. 2000, AECS 2000); the idea here is that all individuals own the "rights" to the atmosphere, and each individual should receive an equal amount of the rent generated when rights are auctioned off.

1.2.1 Equilibrium.

Under emissions permits (denoted *EP*) firms choose emissions reductions to minimize the sum of abatement costs and the opportunity cost of using permits to cover emissions (rather than selling them). Thus they set marginal abatement costs equal to the permit price. The private cost of producing a unit of *D* increases by the abatement costs and the opportunity costs of permits—that is, triangle $c(a)$ plus the rectangle τe in Figure 1(a)—and these costs are fully reflected in higher prices as firms are competitive (e.g., Spulber 1985).[12] Thus:

$$(9) \qquad c'(a^{EP}) = \tau \Rightarrow e^{EP} = e_0 - \left\{\frac{\tau}{\gamma}\right\}^{\frac{1}{\theta-1}};\, p^{EP} = p_0 + \tau e^{EP} + c(a^{EP});\, E^{EP} = e^{EP} D(p^{EP})$$

In this equilibrium the (net of tax) profit income for a household in group *i* is:

$$(10) \qquad \pi_i = (k_i / N)(1-\lambda)\tau E\,;\, k_1 / I_1 << k_5 / I_5$$

k_i is the fraction of total stockholdings in the dirty good industry held by all households in quintile *i*, where $\Sigma_{i=1}^{5} k_i = 1$, and $(1-\lambda)\tau E$ is aggregate permit rents accruing to firms in the dirty good industry, which are reflected in higher equity values. In general k_i/I_i increases with income; that is, profit income is a higher fraction of total income for higher income households.[13] Positive profits persist despite the competitive equilibrium: the pollution quota acts like a cartel by driving up product prices and limiting entry of new firms (see Spulber 1985 for a formal proof).

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[12] In practice a portion of abatement expenditures may represent fixed capital installation costs, rather than expenditures that vary directly with the level of plant generation. However, our assumption of constant marginal production costs at the industry level may still be reasonable if we view the unit of output as plant generation, and *D* as the total number of plants. Nonetheless, it would be useful to develop a model with fixed costs and variable output at the plant level to explore under what conditions fixed abatement costs are fully passed on in higher product prices.

[13] If profits were the same fraction of income for all households then the profit income generated by grandfathered permits would *not* be regressive.

1.2.2 Burden of emissions permits.

We decompose the net burden under emissions permits for household i, denoted NB_i, into: (a) the initial burden, B_i, which is gross of any income compensation and (b) the income compensation, ΔI_i, from profit income or from government transfers. That is:

$$(11) \qquad NB_i = B_i - \Delta I_i ; \Delta I_i = G_i + \pi_i$$

$$B_i \approx (p - p_0) D_i - \frac{1}{2} \eta_i p_0 D_i^0 \left\{ \frac{p - p_0}{p_0} \right\}^2$$

The initial burden is the loss of consumer surplus under household *i*'s demand curve for the dirty good between the initial and ex post price. This is shown by area *abcd* in Figure 1(b), equal to the first order reduction in surplus from the price increase, rectangle *abed*, plus the second order Harberger triangle *bce* from the reduction in demand. From (4) and (11), we can infer that B_1/I_1 is greater (less) than B_5/I_5 if s_1 is greater (less) than s_5 (to simplify the discussion we assume that all households have the same demand elasticities—this is relaxed in the sensitivity analysis). That is, the initial burden is greater as a share of income for the lowest-income quintile than the highest-income quintile if the former have higher budget shares for the dirty good.

From (7), (8), (10) and (11), we can show that $\Delta I_1 / I_1^0 < \Delta I_5 / I_5^0$ for $G_i = G_i^{PROP}$ and $\lambda <$ 1, because $k_1 / I_1 < k_5 / I_5$. That is, if a positive portion of the permit rents are reflected in higher firm profits, and the remainder obtained by government is returned in a distributionally neutral fashion, the income compensation effect is a smaller portion of income for low-income households than for high-income households. This is because profit income accrues disproportionately to higher income groups.

We distinguish three notions of a regressive policy. Under a "strongly regressive" policy the net burden is positive for the lowest-income quintile and negative for the highest-income quintile. Under an "intermediate regressive" policy the net burden is positive for the highest income quintile but smaller in absolute terms than that for the lowest-income quintile. And under a "moderate regressive" policy the net burden for the highest-income quintile is larger than that for the lowest-income quintile in absolute terms, but less as a proportion of income.

1.3. Other Environmental Policies

The distributional effect of other environmental policies is fairly straightforward. Under performance standards and technology mandates the price of the dirty good rises only because of abatement costs—there are no scarcity rents. The degree of regressivity or progressivity simply depends on the relative budget shares (and price elasticities) for polluting goods for different income groups. Under a tax on emissions or dirty inputs all the policy rents accrue to the government and, if they are recycled in proportion to income, again whether the policy is regressive or progressive depends on relative budget shares.

In comparing emissions permits with other policies we therefore focus on a slightly different issue. For a given total emissions reduction we examine whether low- and high-income households are worse off or not under emissions permits than under other policies. Clearly, given our two cases for revenue recycling in (8), low-income households are worse off under grandfathered permits than under an emissions tax, as the permit rents accruing to firms go disproportionately to the better off. But whether low-income groups are worse off under permits than under a performance standard, technology mandate and dirty input tax, is ambiguous. These other policies do not transfer wealth to shareholders, but they are more costly in terms of economic efficiency. That is, the abatement cost portion of the price increase for the dirty good is larger under these polices than under permits.

1.3.1 Emissions tax.

We do not explicitly model this policy; it is simply equivalent to emissions permits with $\lambda = 1$.

1.3.2 Performance standard.

Under this policy (denoted *PS*), firms choose abatement a^{PS} to minimize abatement costs $c(a)$ in (6), subject to the constraint $a^{PS} = e_0 - e^{PS}$, where emissions per unit e^{PS} is specified exogenously by the government. The price of the dirty good and emissions are:

(9^PS) $$p^{PS} = p_0 + c(a^{PS});\, E^{PS} = e^{PS} D(p^{PS})$$

The price of the dirty good rises because of abatement costs only; there are no scarcity rents corresponding to rectangle τe in Figure 1(a). For a given total emissions reduction, final output does not fall by as much as under emissions permits (because the price increase is smaller); therefore the reduction in emissions per unit of output, and hence the value of *c*(.), must be greater under the performance standard for a given reduction in *E* (see Spulber 1985 and Goulder et al. 1999 for formal proofs). However, the difference in *c*(.) under the two policies is small in our simulations below (nearly all of the reduction in *E* comes from reducing emissions per unit rather than reducing final output under both policies).[14] The net burden for a quintile under the performance standard is obtained from (9^{PS}), (4) and (11), with $\Delta I_i = 0$.

1.3.3 Technology mandate.

To analyze this policy (denoted *TM*), and the input tax, we distinguish two types of activity for reducing emissions per unit of output: end-of-pipe abatement, for which the cost function is $c_a(a_a) = (1+\mu)\gamma a_a^{\theta}/\theta$, and input substitution, for which the cost function is $c_s(a_s) = (1+\mu)\mu^{-1}\gamma a_s^{\theta}/\theta$. Here $\mu > 0$ is a parameter reflecting the cost of end-of-pipe abatement relative to input substitution. The envelope of these curves (i.e. the cost function in (6)), and the cost-minimizing solutions for a_a and a_s are:

$$(12) \qquad c(a) = \underset{a_a, a_s}{Min} \quad c_a(a_a) + c_s(a_s) \quad \text{s. t.} \quad a = a_a + a_s \Rightarrow a_a^* = \frac{a}{1+\mu}; \;\; a_s^* = \frac{\mu a}{1+\mu}$$

Consider a policy that requires firms to do a given amount of abatement activity $a^{TM} = e_0 - e^{TM}$ through end-of-pipe treatment.[15] For this case price and emissions are:

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[14] In practice firms have different abatement costs and, since a performance standard applies equally to all firms, it will lead to too much abatement at high-cost firms, and too little at low-cost firms (compared with tradable emissions permits). In this regard our homogeneous firm model understates the overall efficiency cost, and price increase, under the performance standard. The same point applies to the technology mandate (see Burtraw and Cannon 2000 for more discussion).

[15] We assume that the regulator picks the most efficient technology for firms, which may not be the case in practice; in this regard we may understate the costs of a technology mandate relative to other policies.

$$(9^{TM}) \quad p^{TM} = p_0 + c_a(a^{TM})\,; E^{TM} = e^{TM} D(p^{TM})$$

For a given total emissions reduction, the price increase is higher under this policy than under the performance standard because abatement costs are higher when options for input substitution are not exploited (i.e. the cost curve $c_a(.)$ lies above $c(.)$). The price increase (and reduction in output) could be larger or smaller than under emissions permits depending primarily on whether $c_a(a^{TM})$ is larger or smaller than $\tau e^{EP} + c(a^{EP})$. The net burden for a quintile is obtained from (9^{TM}), (4) and (11), with $\Delta I_i = 0$.

1.3.4 Input tax.

Finally, we consider a tax on polluting inputs (denoted *IT*) used to produce the dirty good, where the tax is levied in proportion to the pollution content of inputs. The tax is *t* per unit of pollution content, equivalent to *te* per unit of output. The tax encourages a reduction in *e* through input substitution, but not through end-of-pipe treatment, hence the relevant cost curve is $c_s(.)$. For emissions abatement $a^{IT} = e_0 - e^{IT}$, the product price, emissions per unit, total emissions, and government revenue under this policy are:

$$(9^{IT}) \quad p^{IT} = p_0 + te^{IT} + c_s(a^{IT})\,; \;\; e^{IT} = e_0 - \left\{ \frac{\mu}{1+\mu} \frac{t}{\lambda} \right\}^{\frac{1}{\theta - 1}}; \;\; E^{IT} = e^{IT} D(p^{IT})\,; \;\; R = te^{IT} D(p^{IT})$$

For a given reduction in total emissions *E*, the reduction in emissions per unit of output is smaller under the input tax than under emissions permits, as the policy does not exploit end-of-pipe abatement. Consequently, more of the reduction in *E* comes through a reduction in final output under the input tax, i.e. the increase in product price is greater (again these are established results in the literature—see e.g., Goulder et al. 1999). The net burden for a quintile under this policy is obtained from (4), (8), (9^{IT}) and (11) with $\Delta I_i = G_i$.

2. Benchmark Parameters

We use data on the Consumer Expenditure Survey to divide households into quintiles according to total expenditure (our measure of lifetime income), and to obtain household budget shares and the distribution of stock ownership. We calibrate the model, albeit very crudely, to the control of SO_2, carbon and NO_x from the electricity sector (i.e. three independent calibrations) using simulation results from Haiku, a detailed model of the electricity market discussed in Burtraw et al. (2001), Carlson et al. (2000), Banzhaf et al. (2002) and Paul and Burtraw (2002). The benchmark parameters are summarized in Table 1. In the sensitivity analysis we consider a range of alternative scenarios.

2.1 Income distribution.

Previous studies of the distributional effects of environmental policies usually use proxies for annualized lifetime or "permanent" income, as these are a better measure of individual well-being than current income.[16] We follow Poterba (1989, 1991a and b) by using consumption to proxy for annualized lifetime income.[17]

We use data from Harris and Sabelhaus (1997), which is based on 2959 observations from the 1997 Consumer Expenditure Survey (CES), aggregated over four quarters. The sample is meant to be representative of national averages. The sample was divided into quintiles

[16] Annual income differs from permanent income because earnings rise over the life cycle and because of transitory factors (e.g. temporary layoffs). Spending on polluting goods tends to be a smaller portion of the budget of young and older individuals when their income is measured on an annualized lifetime basis rather than current income (e.g., Poterba 1991a and b).

[17] The consumption measure reflects spending power net of the effect of the tax system. But it is far from a perfect measure of well-being. For example, if, due to capital market imperfections, young workers are liquidity constrained, their consumption will understate their annualized lifetime income (e.g., Zeldes 1989). In addition, high-income households end their lives with considerable wealth and, if they gain utility from bequests, consumption may significantly understate their well-being.

Some other studies have used econometric methods relating income to education and other socioeconomic and demographic variables to construct more sophisticated measures of lifetime income (e.g., Fullerton and Rogers 1993, Casperson and Metcalf 1994, Walls and Hanson 1999, and Slesnick 1994). Our objective is to obtain some quick estimates of budget shares and stock ownership across low- and high-income households that can serve as a benchmark, and for this purpose we stick with the simpler consumption measure.

according to household consumption, with equal numbers of households in each quintile.[18] The mean household consumption within a quintile was $10,294 for the lowest income quintile, $18,404 for the next lowest, $25,856 for the middle income, $36,462 for the second richest and $62,453 for the highest income quintile. Average consumption per household across all quintiles is $30,694.

We use consumption as the basis for the government recycling revenues back to households in proportion to their "income". For our purposes, this is the right measure for distributionally neutral recycling. In practice recycling revenues on the basis of observed income is probably a more realistic scenario, though it would be regressive in the sense that the ratio of observed income to consumption ("true" income) increases with income.

2.2 Budget shares for electricity.

We aggregated spending on electricity across all members in a quintile in 1997 and divided by the value of total consumption of that quintile. This gave budget shares of 0.059, 0.045, 0.034, 0.029 and 0.021 for the lowest to highest income quintiles respectively. However direct household consumption accounts for only 42% of total electricity sales: the remainder is split about equally between industrial and commercial users, and is effectively an intermediate good in the production of goods in general.[19] We assume that the use of other electricity drives up the price of consumption goods in general (rather than goods disproportionately favored by low-income groups), and therefore the budget shares for this component of electricity sales are taken to be equal across households. Making this adjustment implies each household's budget shares increase in absolute terms by 0.037. This gives the shares reported in Table 1. The budget share for the top income quintile is 60% of that for the lowest income quintile, implying that the initial burden of policies will be regressive.

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[18] Consumption includes food, clothing, rent and utilities, out of pocket medical, motor vehicles and parts, furniture and household equipment, housing interest and property taxes, housing intermediate goods, life insurance premiums, gifts to organizations, personal interest expenses and other goods and services.

[19] See see www.eia.doe.gov/cneaf/electricity/epav1/ta5p1.html.

2.3 Stock ownership.

We calculate stock ownership by aggregating the value of stocks, bonds, retirement assets, etc. reported by each household in the CES, aggregated for each quintile, and expressed as a fraction of the total value of stockholdings. According to this calculation, the top income quintile owned 53% of stockholdings, while the lowest income quintile owned 3.5% (see Table 1). Ideally, since we are calibrating emissions control policies to the electricity sector, we would use information on the distribution of electricity stock ownership across households rather than total stock ownership. However this is particularly difficult to obtain because households hold the bulk of these stocks indirectly through large institutional investors.[20]

2.4 Government share of permits rents.

Profit income is taxed at the firm level through corporate income taxes and at the household level through federal and state income taxes of dividends and capital gains taxes. There is uncertainty about the overall effective tax rate due to the variability of personal and corporate rates with income and various exemptions (e.g. deferred payments for assets accumulating in retirement accounts). Judd (1987) uses a range of 0.3 to 0.5 for the effective tax on profits, while Lucas (1990) uses 0.35. For the case of grandfathered permits we assume λ = 0.35.

2.5 Electricity data.

Multiplying the budget shares in Table 1 by income and aggregating over households (there are 21,176,904 households per quintile nationwide) gives total electricity expenditure, D_0,

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[20] Dinan and Rodgers (2002) also used data on aggregate stockholdings, however they looked at current capital income only. Thus, their definition of capital excludes assets held in retirement accounts, which are more evenly dispersed among income groups than non-retirement financial capital. In their analysis the top income quintile owns 86% of stocks; consequently grandfathered permits are more regressive.

of \$218 billion. In 1997 the retail price for electricity, p_0, was \$68.5/MWh.[21] Thus, D_0 = 3,178 million MWh.

In the Haiku model the price elasticity for electricity η is –0.25, and we use this for our starting value. This is a combined estimate averaged across regions, time blocs, and residential, commercial, and industrial users, though it might be conservative as it represents a short to medium run rather than long run estimate. But our results are not sensitive to higher values (see below).

2.6 Emissions and Abatement costs.

The Haiku model is benchmarked for 2010, although cost estimates are expressed in current dollars. We assume that the (marginal) costs of a given proportionate reduction in emissions are the same today as in 2010. We also assume the marginal abatement cost functions are linear, i.e. $\theta = 2$. This actually seems a reasonable approximation for carbon emission reductions up to about 30%, SO_2 reductions up to about 85% and NO_x reductions up to about 60% (see Burtraw et al. 2001, Figure 2, and Banzhaf et al. 2002, Figures 2a and 2b).[22]

When fully phased in, Title IV of the 1990 Clean Air Act Amendments places a cap of about 9 million tons on power plant emissions of SO_2. This represents a reduction of around 44% below baseline levels (E_0 = 16 million tons), and in current dollars the equilibrium permit price τ is estimated at \$290 (Carlson et al. 2000). Dividing emissions by output and plugging these numbers into $\gamma(e_0 - e^{EP}) = \tau$ gives γ.[23] Roughly speaking, about half of the emissions reduction

[21] From www.eia.doe.gov/cneaf/electricity/epav1/ta6p1.html.

[22] If the marginal abatement cost curve were convex rather than linear, this would increase the size of permit rents relative to the pure abatement costs and strengthen our results, for a given point estimate of the marginal cost of abatement. This can be seen from Figure 1(a) by drawing the marginal abatement cost curve as convex, while still passing through the origin and (a, τ).

[23] In obtaining values for γ for all three pollutants we assume that output is the same with and without the emissions cap. This is reasonable based on Haiku because output changes by around 1% or less for the policy simulations that we use for calibration. However in our actual simulations output does vary—though only modestly—as we change the amount of emissions reduction.

to date has been from substituting low-sulfur coal for high-sulfur coal and about half from post-combustion scrubbing; therefore we choose $\mu = 1$ (e.g., Carlson et al. 2000). For this case we assume the technology mandate is a scrubber, and the input tax is a tax in proportion to the (ex ante) sulfur content of coal—the input tax encourages the optimal use of low-sulfur coal, but not any scrubbing.

In the Haiku model baseline carbon emissions are 520 million tons, with 86% of those emissions from coal and oil generating plants, 14% from gas, and none from other fuels. A system of (auctioned) carbon permits that yields a permit price of $50/ton reduces emissions about 10% below baseline levels.[24] These numbers imply $\gamma = 3056$. Nearly all of the reduction in carbon emissions per unit of electricity comes from substituting gas-fired generation for coal-fired. Currently there are no economically viable scrubbing technologies; hence we do not consider a technology mandate for this case ($\mu = \infty$). We also do not explicitly consider a tax on the carbon content per unit of inputs, as this would be equivalent to auctioned emissions permits in our model.

In 1998 a cap-and-trade program was introduced to reduce summertime power plant emissions of NO_x from 19 eastern states. The program is estimated to reduce nationwide annual emissions by 22% below baseline levels of around 5.4 million tons; if the program were extended to cover emissions year round (which would make sense from a benefit/cost perspective) national emissions would fall by around 43% (Burtraw et al. 2000). As a compromise, and to differentiate the benchmark abatement scenario from SO_2, we consider an emissions reduction of 30%. We assume the permit price at this emissions reduction is $700/ton.[25] Around 70% of these reductions come from technology adoption (low NO_x burners and post-combustion scrubbers installed at coal and gas plants) and most of the remainder from fuel substitution. From (12) this implies $\mu = 0.429$. For this case we assume the technology mandate leads to the efficient adoption of NO_x reducing technologies, while the input tax is on the (ex ante) NO_x content of fuels.

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[24] Based on (unpublished) simulations that update results in Burtraw et al. (2001), Figure 2. The original US pledge to reduce national carbon emissions to 7% below 1990 levels by 2010 would imply emissions reductions below baseline levels of around 30% (EIA 1999). This target has proved to be politically unacceptable with the US withdrawal from Kyoto in 2002; hence we consider a more modest target to begin with.

[25] Based on Banzhaf (2002), Figure 2b.

The model is easily solved by starting with a given permit price, then calculating emissions per unit, followed by abatement costs, price, demand, total emissions, government transfers, and finally the net burdens, using (2), (4), (5), and (7)-(11).

3. Results

3.1 Emissions Permits

3.1.1 Benchmark results.

Table 2 shows the distributional burden under our benchmark parameter assumptions for SO_2, carbon and NO_x. The percentage reductions in total emissions are 10% for carbon, 30% for NO_x and 44% for SO_2.[26]

The carbon policy is strongly regressive, regardless of how the portion of permit rents obtained by the government is recycled. And at least for distributionally neutral recycling, the NO_x policy is strongly regressive while the SO_2 policy is intermediate regressive. Under the carbon policy the initial burden for the top income quintile is \$406, nearly four times that for the lowest income quintile, but nearly all of this is offset by profit income of \$370, and taking account of government recycling there is a net gain for the richest households of \$39 to \$117. For the lowest income quintile the profit income is only \$24, and overall they are worse off by between \$6 and \$56. Similar qualitative results apply to NO_x, although the dollar figures involved are much smaller. Under SO_2 there is a positive net burden for the top income households, but as a portion of income, it is only between 1% and 32% of the burden for the lowest income quintile.

[26] The reductions in emissions per unit of output are slightly lower than these figures because output changes, though only by a small amount. Electricity output is 3093, 3166 and 3167 MWH respectively under the carbon, SO_2 and NO_x policies, compared with the pre-regulation level of 3178 MWh.

3.1.2 Alternative abatement levels.

Figure 2 illustrates how the (absolute) net burden for the top income quintile, expressed relative to that for the bottom income quintile, changes as we vary the emissions reduction for each pollutant between 0 and 70% (for proportional revenue recycling).

Grandfathered emissions permits are strongly regressive for all pollutants for emissions reductions below about 40-50% (i.e. the curves lie below the horizontal axis because *NB* for the top income group is negative). Below emissions reductions of below about 60-65% emissions permits are at least intermediate regressive for all three pollutants (i.e. the curves are less than unity because *NB* for the top income group is less than that for the bottom income group). And even at a 70% emissions reduction the net burden for the top income group is less than double that for the lowest income group, even though their income is six times as large. The degree of regressivity is especially large at low amounts of abatement as permit rents, and hence the windfall gains to the top income group, are a relatively large portion of the initial burden. That is, τe is large relative to $c(a)$ in Figure 1(a), or *abfg* in Figure 1(b) is a large portion of trapezoid *abcd*. As abatement increases the relative magnitude of the permit rents declines; pure abatement costs are responsible for a greater portion of the product price increase and the initial burden. At the limit of 100% abatement there would be no rents generated and no windfall gains to the top income quintile.

The other main point from Figure 2 is that the curves are very close together; in fact those for SO_2 and NO_x are virtually indistinguishable. That is, for a given level of abatement the degree of regressivity is more or less the same for all three pollutants. This is because the portion of the product price increase due to permit rents is about the same for all three pollutants at a given emissions reduction.

3.1.3 Budget shares.

Not all of the regressivity of grandfathered permits is due to the wealth transfer to high-income groups; part of it is because low-income groups have relatively high budget shares for polluting goods. In Table 3 we illustrate how the benchmark results in Table 2 would change if instead all income groups have the same initial budget shares (for the case of proportional recycling).[27] The carbon policy is still strongly regressive. However, the net burden for the lowest income quintile is reduced by more than 50%, while the net gain for the top income quintile is reduced by 50% or more. The SO_2 policy changes from intermediate regressive to moderate regressive, and the NO_x policy from strongly regressive to intermediate regressive.

3.1.4 Government share of rents.

In Figure 3 we show the net burden for the top income quintile relative to that for the bottom income quintile as we vary the share of permit rents accruing to the government between 0 and 1. To isolate the effect of the wealth transfer we set all the household budget shares equal (to 0.067), and assume proportional revenue recycling.

The relative net burden for the top income quintile increases as the portion of rents accruing to the government rises (and that accruing in profit income declines). At the extreme when all rents go to the government the net burden is proportional to household income for all policies; all three curves converge at 6.1, the ratio of income for qunitile 5 to that for quintile 1. But the main point from Figure 3 is that for the carbon policy the government has to obtain at least 80% of the permit rents to prevent the policy from being strongly regressive; for NO_x it has to obtain 30% of the permit rents.

3.1.5 Further sensitivity analysis.

Table 4 provides some further sensitivity analysis. It shows how the net burden for the top and bottom income quintiles—for the case of carbon with proportional recycling—varies with demand elasticities, abatement costs, and stock ownership.

The results are not very sensitive to varying the demand elasticities, either for all households, or for poor households versus rich households (i.e. triangle *bcd* in Figure 1(b) is always small relative to rectangle *abed*). Varying the slope of the marginal abatement cost curve in Figure 1(a) affects the electricity price, and hence the net burden for all income groups, by the

[27] To keep initial aggregate electricity demand the same this budget share must be 0.067.

same proportion; it does not affect the net burden for one group relative to that for another. The results are, not surprisingly, sensitive to the distribution of stock ownership. For example, if the top income quintile owned 80% of stocks rather than 53%, their net gain would be \$311 rather than \$117.

3.2 Comparison with Other Instruments

Table 5 shows the net burden for quintiles 1 and 5 under all five emissions control instruments, given our benchmark scenarios for parameters and abatement levels. The table shows that the top income quintile is always better off (or not as worse off) under grandfathered permits than other policies, and by a large amount. For example, under SO_2 control the net burden on quintile 5 is anywhere between 1.9 and 34 times as large under other policies than under grandfathered permits. Conversely, at least for the case of proportional revenue recycling, the bottom income quintile is worse off under grandfathered permits than under other instruments, with the exception of the input tax.

The reasons for these results are straightforward. Unlike grandfathered permits, the other policies do not transfer wealth in favor of quintile 5 through higher profit income. The bottom income quintile receives more income compensation from the government under the emissions tax than under grandfathered permits. And under the performance standard and technology mandate quintile 1 bears a smaller initial burden as there are no permit rents reflected in higher product prices. The initial burden on quintile 1 under the input tax is larger than under grandfathered permits;[28] but these households receive a larger transfer from the government. Quintile 1 is worse off with the input tax than with grandfathered permits under proportional recycling but better off with the input tax under lump sum recycling.

The net burdens under the input tax and technology mandate vary with different values for μ, while the net burden under other policies do not. For example, a higher value for μ raises the relative cost of end-of-pipe abatement and lowers the relative cost of input substitution: that

[28] For a given emissions reduction abatement costs, and hence product prices, are higher as the input tax fails to exploit end-of-pipe abatement options.

is, it raises the net burden (for all quintiles) under the technology mandate and lowers if for the input tax.

4. Distributional Effects and the Social Costs of Environmental Policies

We now compare the social costs of emissions permits with the pure efficiency costs, and with the social cost of other environmental policies, under different assumptions about society's aversion to inequality. To do this we derive distributional weights for income groups from a social welfare function. The use of distributional weights in policy evaluation is highly controversial and problematic, and we make no judgment about what set of weights, if any, might be appropriate. Our purpose is simply to illustrate what different societal preferences would imply for social costs. [29]

4.1 Social Welfare Function.

We simplify by assuming that households have CES utility functions—therefore utility is proportional to income—and that households have identical preferences. Under these restrictions social welfare can be expressed in terms of household income, and social preference parameters, but independently of individual preference parameters. We adopt the following social welfare function: [30]

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[29] One problem is that it is difficult to assess to what extent income inequality is due to luck (natural ability, family circumstance, etc.) as opposed to effort by individuals (willingness to work hard, accumulate human capital etc.). See Fong (2001) and Picketty (1995) for some recent discussion on this.

In fact it is very difficult to assess society's preference for redistribution. It is possible to infer a set of distributional weights by exploring how much economic efficiency the government is willing to sacrifice to have a progressive, distortionary income tax system (see Gruber and Saez 2002 for a recent illustration). However the tax system is at least partly determined by the interplay of interest groups, rather than purely benevolent government behavior, implying that these type of estimates may be an unreliable indicator of society's true preferences.

[30] For similar formulations see e.g. Atkinson and Stiglitz (1980), pp. 340, Heady (1993), pp. 20, and Mayeres (2001).

$$(13) \qquad W = \begin{cases} (1-\beta)^{-1}\Sigma_{i=1}^{5N}(I_i^{1-\beta} / \bar{I}^{-\beta}) & \beta \neq 1 \\ \Sigma_{i=1}^{5N}\log(I_i / \bar{I}) & \beta = 1 \end{cases} \qquad \bar{I} = \Sigma_{i=1}^{5N} I_i \ / 5N$$

where W is social welfare (in dollars), and $\bar{I}$ is mean household income. β is a "preference for equality" parameter. When $\beta = 0$ social welfare equals the sum of individual income, thus changes in the distribution of welfare have no effect on W (a standard assumption implicit in regulatory cost assessment). When $\beta > 0$ social welfare is increased (reduced) when income is redistributed towards (away from) low-income households.

Differentiating (13) gives:

$$(14) \qquad \frac{\partial W}{\partial I_i} = \left\{ \frac{I_i}{\bar{I}} \right\}^{-\beta}$$

This is the social welfare weight attached to changes in household i's income, or net burden from emissions control policies (the weight would always be unity for a household with mean income). We consider cases where $\beta = 0$, 0.5 and 1. Given the income distribution in Table 1, when $\beta = 0.5$ the weights for the lowest and highest income quintiles are 1.73 and 0.70 respectively and when $\beta = 1$ they are 2.98 and 0.49. The social cost of emissions control policies is calculated by:

$$(15) \qquad \Sigma_{i=1}^{5N} NB_i \frac{\partial W}{\partial I_i}$$

that is, the sum of net burdens, where net burdens are multiplied by the distributional weights.

4.2 Results.

Table 6 computes the formula in (15) for our benchmark parameter values, abatement levels, and the different emissions control policies. The first column, when $\beta = 0$, shows the pure efficiency costs of the policies (ignoring distributional effects). Here the emissions tax and emissions permit policies are equivalent; for SO_2 and NO_x the performance standard is slightly more costly than emissions permits and the technology mandate and input tax are substantially more costly.

The social costs of grandfathered permits can be substantially increased if society has aversion to inequality. For example, the social costs of carbon policies increase from $1,310 million to $3,262 million when $\beta = 0.5$, and to $5,702 million when $\beta = 1$, for proportional recycling. The social costs of emissions taxes with proportional recycling can also increase substantially—though by less than under grandfathered permits—as this policy is still regressive, because of the relatively high budget shares for low-income households. But if revenues are returned in a progressive fashion—in equal lump-sum transfers—the social costs of the emissions tax are much lower, and negative in the case of carbon and NO_x.

Finally, when society has aversion to income inequality the cost-effectiveness ranking of grandfathered permits relative to policies that are inefficient from a pure efficiency perspective may change. For example the performance standards for SO_2, carbon, and NO_x are more costly than grandfathered permits on pure efficiency grounds, but less costly in most scenarios when $\beta = 0.5$ and 1.[31]

5. Conclusion

This paper, building on earlier work by Dinan and Rogers (2002), demonstrates the potential importance of equity considerations for the choice of grandfathered emissions permits versus other policy instruments for environmental protection. If society cares about adverse changes in the distribution of income, there is a potentially strong case for using emissions taxes, or auctioned emissions permits, in preference to grandfathered permits (assuming revenues are not used for pork-barrel spending projects). Indeed if revenue recycling occurred through broad income tax reductions, potentially there is both a strong equity and efficiency argument for using emissions taxes or auctioned permits.

We finish off by mentioning some caveats, in addition to those already emphasized.

The analysis simplifies by ignoring additional excess burdens of environmental policies from fiscal interactions. These arise from the impact of pollution control policies on increasing

[31] Of course an inefficient means of regulation can never be optimal from a welfare point of view; it can always dominated by an efficient instrument that avoids perverse redistribution schemes.

product prices, reducing real household wages and labor supply, hence exacerbating pre-existing tax distortions in the labor market. On the other hand efficiency gains would arise to the extent that revenues from environmental policies were used to reduce income taxes, hence increasing labor supply, and other distortions of the tax system such as the bias for tax-favored spending (e.g., employer provided medical insurance, owner occupied housing). A fruitful area for future research would be to explore how these additional efficiency losses and gains might be distributed across households.

Our focus is purely on the cost side of environmental policies; assessing who benefits the most from a cleaner environment is a difficult task.[32] And our use of social welfare weights to value distributional effects is highly controversial, though our purpose is simply to illustrate the implications of different assumptions. Finally, we focus on the use of household income, that is, the costs of goods purchased by different households. A more general model might explore how environmental policies affect the return to labor for different household groups; for example, if polluting industries disproportionately employ low-skill workers, they may impose an additional burden on low-income households.

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[32] For example, the poor often live in the most polluted parts of cities and may benefit more from improved urban air quality. However, cleaner air may drive up rents, thereby displacing low-income renters. See Gianessi et al. (1979) for more discussion.

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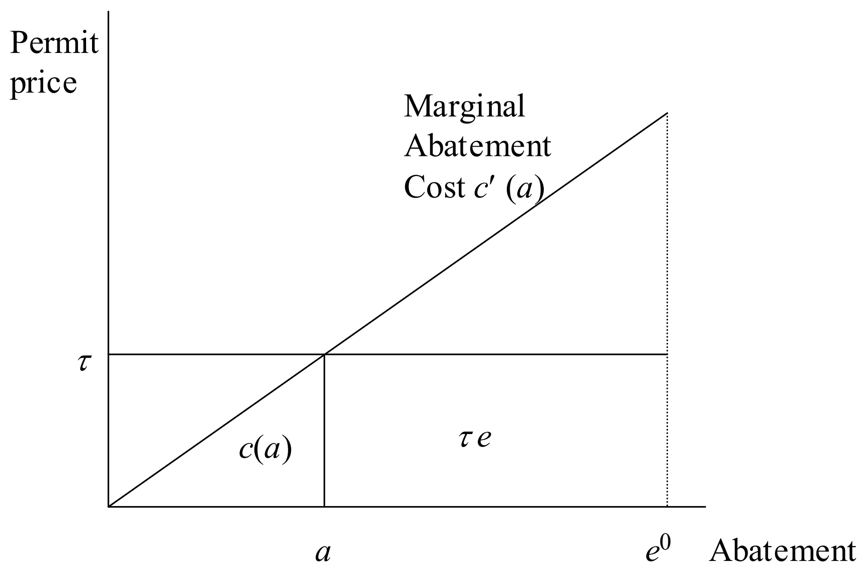
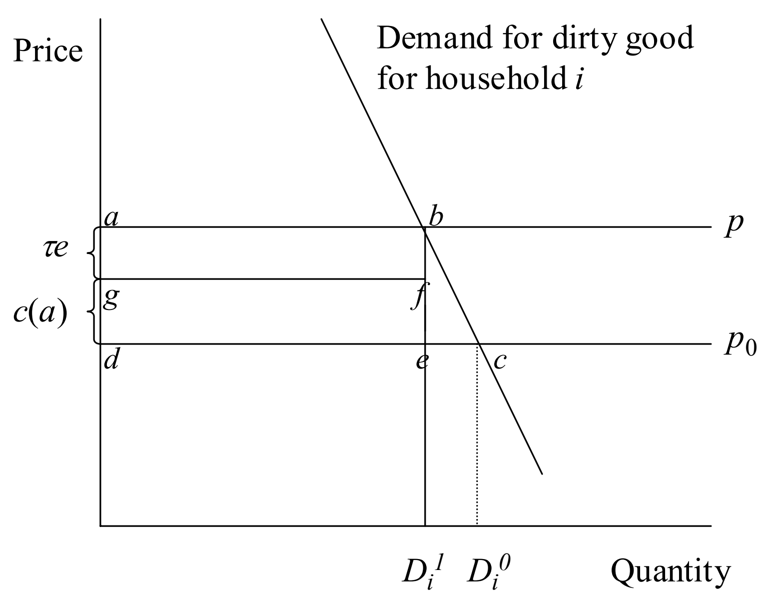
Figure 1.



(a) Firm abatement under emissions permits



(b) Initial Burden to Household *i* under Emissions Permits

Figure 2. Relative Net Burden and Abatement Level

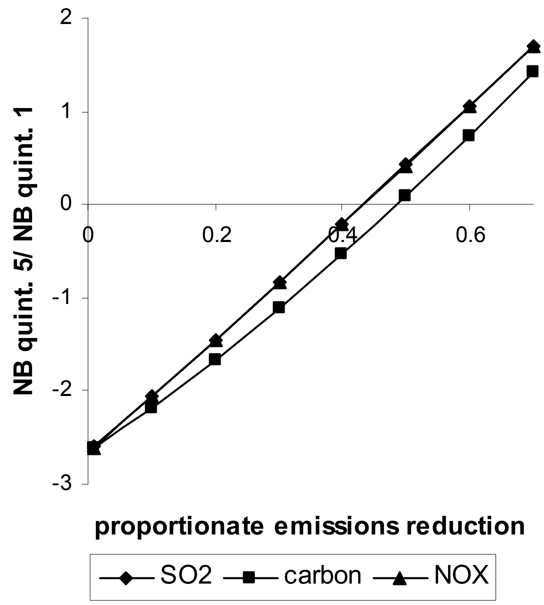


Figure 3. Relative Net Burden and Government Rent Share

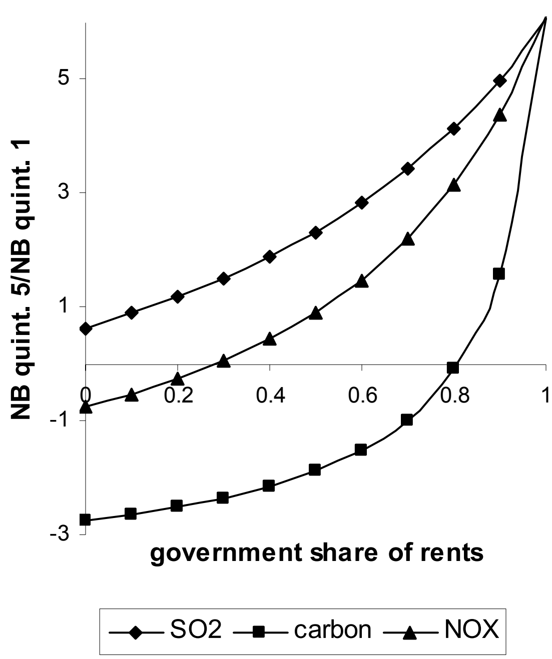


Table 1. Benchmark Parameter Values

		income $ I_i	Electricity budget share s_i	fraction of stocks k_i
Income quintile	1	10,294	0.096	0.035
	2	18,404	0.081	0.111
	3	25,856	0.070	0.091
	4	36,462	0.065	0.234
	5	62,453	0.058	0.529
	mean	30,694		
				1.0
Government share of permit rents λ			0.350	
Baseline electricity price p_0, $/MWh			68.5	
Baseline electricity output X_0, mn MWh			3178	
Electricity price elasticity			-0.25	
Abatement cost parameter, θ			2	
SO_2 parameters				
Baseline emissions, mn tons			16	
Emissions cap, mn tons			9	
Permit price at cap, $/ton			290	
abatement cost parameters		γ	131678	
		μ	1	
Carbon parameters				
Baseline emissions, million tons			520	
Emissions cap, million tons			468	
Permit price at cap, $/ton			50	
abatement cost parameters		γ	3056	
		μ	∞	
NO_X parameters				
Baseline emissions, million tons			5.4	
Emissions cap, million tons			3.78	
Permit price at cap, $/ton			700	
abatement cost parameters		γ	1373402	
		μ	0.429	

Table 2. Distributional Burden per Household from Emissions Controls

		Income quintile				
		1	2	3	4	5
SO_2 (44% reduction)						
Initial burden, $		16	25	30	39	60
Profit income, $		3	9	7	19	42
Net burden, $	proportional recycling	11	11	16	11	1
	% of income	0.104	0.058	0.060	0.029	0.001
	Lump-sum recycling	5	7	14	12	9
	% of income	0.048	0.039	0.055	0.033	0.015
Carbon (10% reduction)						
Initial burden, $		106	160	200	266	406
Profit income, $		24	78	64	164	370
Net burden, $	proportional recycling	56	37	73	13	-117
	% of income	0.546	0.202	0.282	0.035	-0.187
	Lump-sum recycling	6	7	61	27	-39
	% of income	0.061	0.038	0.236	0.073	-0.063
NO_X (30% reduction)						
Initial burden, $		14	22	26	35	53
Profit income, $		3	9	7	19	43
Net burden, $	proportional recycling	9	8	12	6	-7
	% of income	0.084	0.041	0.046	0.015	-0.011
	Lump-sum recycling	3	4	10	7	2
	% of income	0.028	0.022	0.040	0.020	0.003

Table 3. Sensitivity with respect to Budget Shares
(net burden with proportional recycling)

		Income quintile				
		1	2	3	4	5
Budget shares		**0.067**	**0.067**	**0.067**	**0.067**	**0.067**
Net burden						
SO_2	$	6	6	14	12	10
	% of income	0.056	0.035	0.055	0.032	0.016
Carbon	$	27	14	64	17	-60
	% of income	0.258	0.074	0.249	0.047	-0.096
NO_X	$	4	4	11	7	1
	% of income	0.042	0.021	0.042	0.019	0.002

Table 4. Further Sensitivity Analysis
(carbon, with proportional recycling)

	NB for quintile 1 , $	**NB for quintile 5**, $
1. Benchmark	56	-117
2. Demand elasticites		
halved	60	-124
doubled	58	-118
η_1= -0.125, η_5 = -0.5	62	-127
η_1= -0.5, η_5 = -0.125	56	-117
3. Abatement costs		
γ halved	30	-62
γ doubled	116	-237
4. Stock ownership		
k_1 = .01, k_5 = .80	77	-311
k_1 = .07, k_5 = .40	35	-32

Table 5. Net Burden per Household Under Alternative Policies
($)

	quintile 1		quintile 5	
	proportional recycling	lump-sum recycling	proportional recycling	lump-sum recycling
SO_2				
grandfathered permits	11	5	1	9
emissions tax	8	-8	10	36
performance standard	5	5	17	17
technology mandate	9	9	34	34
input tax	16	-17	21	71
Carbon				
grandfathered permits	56	6	-117	-39
emissions tax	34	-109	-32	191
performance standard	9	9	32	32
technology mandate	na	na	na	na
input tax	34	-109	-32	191
NO_X				
grandfathered permits	9	3	-7	2
emissions tax	6	-10	3	29
performance standard	3	3	9	9
technology mandate	4	4	14	14
input tax	19	-35	9	92

Table 6. Total Social Costs of Pollution Control Policies
($ million)

	β = 0	β = 0.5		β = 1	
		proportional recycling	lump-sum recycling	proportional recycling	lump-sum recycling
SO_2					
grandfathered permits	1018	1255	1084	1636	1241
emissions tax	1018	1138	650	1390	262
performance standard	1026	1030	1030	1133	1133
technology mandate	2041	2048	2048	2253	2253
input tax	2013	2248	1277	2741	496
Carbon					
grandfathered permits	1310	3262	1766	5702	2244
emissions tax	1310	2240	-2035	3549	-6333
performance standard	1943	1949	1949	2144	2144
technology mandate	na	na	na	na	na
input tax	1310	2240	-2035	3549	-6333
NO_X					
grandfathered permits	562	801	626	1140	736
emissions tax	562	682	183	889	-264
performance standard	564	565	565	622	622
technology mandate	805	807	807	888	888
input tax	1777	2142	437	2777	-1163