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Essays on Environmental and Public Economics

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Essays on Environmental and Public Economics

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Dedicated to Mark.

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Essays on Environmental and Public Economics

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This dissertation is a collection of three essays in the fields of environmental and public economics. The first essay assesses the effect of government spending on charitable donations to environmental causes. Using a theoretical model, I solve for changes in private donations due to increased government spending and contrast this with changes due to direct grants to nonprofit organizations. Depending on the nonprofit's fundraising response, government spending may result in the crowding out or in of private giving. I empirically investigate this topic using data from the tax returns of environmental charities as well as a panel survey data set on the philanthropic behavior of individuals. My results indicate that government expenditures on the environment actually crowd in private giving, partly due to the increased fundraising response by charities.

The second essay examines the incidence of a pollution tax scheme in which tax revenue is returned to low-income workers. Using a general equilibrium model with both skilled and unskilled labor, a decomposition of the real net wage effects shows the effect of the tax rebate, the effect on the uses side of income (higher product prices), and the

effect on the sources side of income (relative wage rates). Numerical examples show that returning the revenue to the low-skilled workers is still not enough to offset the effect of higher product prices; in almost all cases, the rebate does not prevent a reduction in the real net wage.

The third essay studies the distributional effects of the SO_2 allowance market. Even if low-income households do not have large budget shares for the polluting good, grandfathered permit systems may still be regressive since the permit rents accrue disproportionately to wealthy shareholders in the polluting industry. I estimate the burden imposed on different income groups under a grandfathered permit policy and compare this with the burden under an auctioned policy. Using Monte Carlo techniques, I calculate the 5^{th} and 95^{th} percentiles of the distribution of possible results. I find evidence of regressivity for grandfathered permits whereas an emissions tax/auctioned permit system can be progressive if the scarcity rents are distributed in lump sums.

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Chapter 1

Environmental Policy and Giving: Does Government Spending Affect Charitable Donations?

1.1 Introduction

Concern for the environment has increased greatly in recent years as people have become more aware of the negative impact their actions have on the environment, and issues such as climate change have gained prominence. In response to this heightened awareness, nonprofit environmental organizations have multiplied in number and have seen their charitable donations surge. Giving to environmental and animal-welfare charities was nearly \$6.2 billion in 2009 (according to *Giving USA*), whereas it was virtually nothing four decades ago. Voluntary donations to environmental causes help to increase the provision of environmental quality and supplement spending by the government for the same purpose. However, little is known about the interaction between government spending and private giving to environmental organizations. Environmental nonprofits may respond to increased environmental expenditures by the government by altering their fundraising efforts, or individuals may choose to give less if they perceive that the government's spending has made their donations less needed. For policy purposes, it is important to understand this relationship and how spending by the government for environmental purposes affects giving to nonprofits.

Using data from the tax returns of environmental charities as well as household-level data on charitable giving, I estimate the effect of environmental policy on charitable donations to green causes. A vast literature exists on the crowding out of private giving by government spending, and the results are largely mixed, with some studies finding evidence of crowding out and others actually finding evidence of crowding in. Much of the recent empirical literature focuses on the role of direct government grants to charitable organizations and the response of private giving to these grants, and very few consider environmental organizations. In this paper, I look at a different, but related, question: how does private giving to environmental causes respond to environmental policy? If the public has incomplete information on government policy and spending, then any changes in environmental giving may be due to the actions of charities, themselves, and not due to a behavioral response by individuals. Therefore, it is important to take nonprofits' fundraising efforts into account when estimating the impact of environmental policy on green giving.

The classic model of crowding out assumes that individuals care only about the overall level of the public good and therefore treat their own contributions and the government's support of the public good as perfect substitutes.[1] As a result, a dollar increase in government funding should decrease private contributions by a dollar. However, most empirical studies have shown that crowding out is actually quite small, nonexistent, or even negative.[2] Andreoni (1989, 1990) developed an impure altruism model that provides intuition for these findings. Instead of assuming that individuals care

[1] Early works on the classic theory of crowding out include Warr (1982), Roberts (1984), and Bergstrom et al. (1986).

[2] See, for example, Kingma (1989), Khanna et al. (1995), Payne (1998), Khanna and Sandler (2000), Okten and Weisbrod (2000), Payne (2001), Hungerman (2005), Manzoor and Straub (2005), Borgonovi (2006), Gruber and Hungerman (2007), Dokko (2008), Heutel (2009), and Andreoni and Payne (2010).

just about the total amount of the public good, they also gain utility from the act of giving, called a "warm glow". This type of model can explain why crowding out is incomplete, i.e., less than one-for-one, and why government funding may actually crowd in private giving.

More recently, the literature has paid greater attention to the role of fundraising and how government grants to nonprofits affect not only donations but also fundraising expenditures. Andreoni and Payne (2003) find that government grants to nonprofits cause a significant decrease in fundraising. If charities respond to increased government grants by reducing their fundraising efforts, then private donors may give less due to the reduced fundraising or because of the classic crowd out explanation. Andreoni and Payne (2010) decompose the effect of government grants on private giving into these two types of crowding out. Using a large panel of social service charities, they find evidence of overall crowding out, but most, if not all, of this is attributable to reduced fundraising. While their study focuses on government grants to charities, it is also possible that nonprofits may respond to other types of government spending that is not given directly to charities but still contributes toward providing the public good.

This paper contributes to the crowding out literature by studying the effect of government spending on private giving as opposed to focusing only on government grants to charities. This less studied type of crowding out may be very different from the kind resulting from grants; in my sample of environmental nonprofits, 54 percent of the observations are from charities that never received any government grants. Few of the recent empirical studies consider crowding out due to direct government spending, and none control for the charities' response to government policy through changes in fundraising.[3] Simmons and Emanuele (2004) use individual-level data on charitable behavior to empirically study the effect of state and local government expenditures on the donation of time and money. They find a negative and statistically significant relationship between government funding and both types of giving; however, in contrast to my study, they have only measures of overall giving and government spending. Using aggregate time-series data, Garrett and Rhine (2010) consider the effect of different levels of government spending on giving to various causes, including health, education and welfare. They find little evidence of a significant relationship between government spending and charitable giving, positing that this might be due to the rational ignorance of individuals.[4]

Additionally, to my knowledge this is the first paper to address the possibility of endogenous government policy, including both direct spending and grants to nonprofits, in the estimation of crowding out. Because unobserved events may lead to altered government spending and private giving, estimates of crowding out due to government policy are likely to be biased. For example, flooding that causes damage to parkland may cause both private giving and public spending to increase, and estimates of the effect of

[3] For some other studies that consider government spending, see Abrams and Schmitz (1984) and Lindsey and Steinberg (1990) who study the impact of state-level social-welfare transfers and state social service expenditures, respectively, on charitable giving. Additionally, Hungerman (2005) estimates the effect of government welfare expenditures on donations to churches, and Gruber and Hungerman (2007) investigate the extent to which New Deal spending crowded out church charitable spending during the Great Depression.

[4] Congleton (2001) argues that the rational ignorance of people, whereby individuals do not know about government spending or taxation because the effort cost of doing so is greater than the benefit, can lead to fiscal illusion.

government spending that do not take this endogeneity into account will overstate the extent of crowding out. Conversely, the government may respond to the flooding damage by increasing government grants to nonprofits and decreasing direct spending; in that case, estimates of the effect of government spending will be negatively biased. This paper uses an instrumental variables approach to address this concern using both charity-level and household-level data.

By focusing on environmental charities, this paper adds to the very small literature on green nonprofits. Environmental charities have significantly different features from other types charities. In a study of the tax returns of environmental and animal-related charities, Straughan and Polk (2008) find that they receive an average of 46 percent of their revenue from private donations and 12 percent from government grants, whereas public nonprofits as a whole receive 12 and 9 percent, respectively. The number of environmental and animal-related charities has also surged in recent years, growing from 6,088 IRS-reporting organizations in 1995 to 13,399 in 2005 (National Center for Charitable Statistics, 2008). These nonprofits have also seen a huge increase in revenues, more than 90 percent after inflation, over the same time period (National Center for Charitable Statistics, 2008). In one of the few empirical papers that studies environmental charities, Heutel (2007) looks at how government grants to nonprofits and private donations may each crowd out the other.[5] For environmental charities, he finds no evidence of government grants crowding out private giving or vice versa.

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[5] For two other studies on environmental nonprofits, see Parker and Thurman's (2010) paper on the effect of federal land programs on private land trust conservation and

In this paper, I present a simple warm glow model of private giving and use it to predict the effect of government spending on giving to environmental causes. I then estimate the presence or degree of crowding out or crowding in by environmental policy using two different data sets, the Panel Study of Income Dynamics (PSID), which in recent years added a philanthropy module to its questionnaire, and a large charity-level data set made available by the National Center for Charitable Statistics (NCCS). Results from both data sets indicate that state environmental spending has a positive effect on charitable giving. Estimates using the charity-level data show that nonprofits respond to increased state spending by increasing their fundraising efforts. After controlling for the charities' response through fundraising, I find that a one dollar increase in per capita state environmental spending increases per capita donations to a nonprofit by 0.2 cents or about 0.01 standard deviations. Although this effect seems small, donations are highly variable; an increase of 0.2 cents in per capita donations represents an increase of about $22,000 in donations (net of fundraising costs) for an environmental charity in an average sized state and is about 3.5% of the mean amount. Results from the household-level data show that the estimated effect of environmental spending on private giving is also positive but no longer significant after controlling for the endogeneity of state spending.

The next section below presents the theoretical model. Section 1.3 describes the nonprofit-level data set, and Section 1.4 describes the estimation strategy for this data. Then Section 1.5 presents and discusses the results. Section 1.6 describes the household-

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Zhang's (2010) study on fundraising productivity and managerial capacity as determinants of private giving.

level data and estimation strategy. Section 1.7 presents these results, and Section 1.8 concludes.

1.2 Theoretical Model

This section presents a simple warm-glow model of charitable giving used to predict the response of individuals to a change in government spending on environmental quality. In the model, the government contributes to the public good, environmental quality, through direct spending as well as through grants to an environmental charity. Individuals purchase a private consumption good and contribute to environmental quality both directly through a donation to the charity and indirectly through a lump-sum tax, which the government levies to finance its spending on the public good. Individuals receive utility both from their voluntary contribution and the overall amount of environmental quality. The economy has N individuals who each maximize a utility function, $U(c_i, Q, q_i)$, where c is the private consumption good, Q is overall environmental quality, and q is an individual's voluntary contribution to Q. I assume that the utility function is concave, so that $U_x > 0$ and $U_{xx} < 0$ for $x = c, Q,$ and q, where U_x denotes the derivative of U with respect to x, and U_{xx} is the second derivative. Additionally, I assume that all cross-partial derivatives, U_{xy}, are positive.

An individual has exogenous income, w_i, and is taxed τ_i so that individual i's budget constraint is $c_i + p(e)q_i = w_i - \tau_i$, where $p(e)$ is the cost incurred by an individual when donating a dollar to the environmental charity and is dependent on the charity's fundraising effort level, e.[6] The cost of donating is decreasing in the charity's effort level, so that $p'(e) < 0$. Although this model has only one charity providing Q, an individual may still face donation costs associated with researching the quality of the charity and its ability to provide Q.

The total amount of environmental quality can be written as the sum of all individuals' voluntary and involuntary contributions, so that $Q = \sum_{i=1}^{N}(q_i + \tau_i)$. The government's contribution to Q, financed by taxes, consists of direct spending on environmental quality, S, and a grant, G, to the environmental charity: $\sum_{i=1}^{N}\tau_i = S + G$. An individual takes as given all other individuals' contributions to Q so that the total amount of environmental quality can be expressed as $Q = q_i + q_{-i} + \alpha G + \beta S$, where q_{-i} is the amount of voluntary contributions made by everyone other than individual i. The parameters α and β denote an individual's awareness of the level of direct spending and government grants, respectively, and are between zero and one. The inclusion of these parameters makes the model more realistic in that individuals often do not have full information on government spending and policies. Additionally, these awareness parameters allow for the possibility of differential responses by individuals to changes in direct spending and grants.

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6 This feature of the model is borrowed from Dokko (2008). Andreoni and Payne (2003) note that while crowding out models usually assume that individuals have complete information about the various charities available and their ability to provide the public good, the prevalence of fundraising supports the existence of prohibitive search costs, such as those related to research on a charity or finding a charity's address. Charities can reduce these search costs by calling or mailing out donation requests to individuals.

Letting $\sum_{i=1}^{N}\tau_i = \tau_i + \tau_{-i}$, the utility function can be rewritten so that individual i chooses q_i to maximize $U(w_i - (\alpha G + \beta S - \tau_{-i}) - p(e)q_i,\ q_i + q_{-i} + \alpha G + \beta S,\ q_i)$. Assuming an interior solution, the first-order condition characterizes the optimal choice of q_i: $p(e)U_c = U_Q + U_q$. Because individuals receive a "warm glow" from donations to Q, the right-hand side of this condition has two terms, the marginal utility of total environmental quality and the marginal utility from an individual's own donation. Thus, each individual chooses a voluntary contribution so that the marginal utility of environmental quality is equal to the marginal utility of the private good, normalized by the price. The change in q_i due to a change in S can be found by implicitly differentiating the first-order condition:

$$\frac{dq_i}{dS} = \frac{p'(e)\frac{\partial e}{\partial S}U_c - p(e)(\lambda+\beta)U_{cc} + (\lambda+\beta+p(e)\beta)U_{cQ} - \beta U_{QQ} + (\lambda+\beta)U_{qc} - \beta U_{qQ}}{p(e)^2 U_{cc} - 2p(e)U_{cQ} - 2p(e)U_{cq} + 2U_{Qq} + U_{QQ} + U_{qq}}$$

where $\lambda = p'(e)\frac{\partial e}{\partial S}q_i$ and reflects the change in the cost of private contributions due to a change in fundraising. In general, this expression cannot be signed without additional assumptions.

In the simplest case, $\frac{\partial e}{\partial S} = 0$, so that direct government spending has no effect on the charity's fundraising effort, and there is no price effect on voluntary giving. Then $\lambda = 0$ and $\frac{dq_i}{dS} = \beta\frac{-p(e)U_{cc} + (1+p(e))U_{cQ} - U_{QQ} + U_{qc} - U_{qQ}}{p(e)^2 U_{cc} - 2p(e)U_{cQ} - 2p(e)U_{cq} + 2U_{Qq} + U_{QQ} + U_{qq}}$. Now the numerator of this expression has all positive terms except for $-U_{qQ}$, and the denominator has all negative terms except for $-2U_{qQ}$. Thus, if U_{qQ} is not too large, i.e., if an increase in environmental quality does not increase the marginal utility of private giving by too much, then $\frac{dq_i}{dS}$ will be negative, meaning that direct government spending crowds out private contributions to environmental quality. If $\frac{\partial e}{\partial S}$ is negative, so that an increase in government spending decreases fundraising, λ will be positive, and individuals will decrease their contributions due to the increased cost of giving. Again, the numerator of $\frac{dq_i}{dS}$ is positive except for the U_{qQ} term, and there will be crowding out of private giving as long as U_{qQ} is not too large. However, if government spending increases fundraising so that λ is negative, the sign of $\frac{dq_i}{dS}$ is difficult to determine even with assumptions about U_{qQ}, and the result may be crowding out or crowding in of private giving by direct government spending.

In order to compare the effect of a change in direct spending to that from a change in the government grant to the environmental charity, I implicitly differentiate the first order condition again to obtain

$$\frac{dq_i}{dG} = \frac{p'(e)\frac{\partial e}{\partial G}U_c - p(e)(\gamma+\alpha)U_{cc} + (\gamma+\alpha+p(e)\gamma)U_{cQ} - \alpha U_{QQ} + (\gamma+\alpha)U_{qc} - \alpha U_{qQ}}{p(e)^2 U_{cc} - 2p(e)U_{cQ} - 2p(e)U_{cq} + 2U_{Qq} + U_{QQ} + U_{qq}}$$

where $\gamma = p'(e)\frac{\partial e}{\partial G}q_i$ is the price effect on private giving due to a change in fundraising as the charity responds to an increased grant. This expression is very similar to $\frac{dq_i}{dS}$, and when $\frac{\partial e}{\partial G}$ = 0, so that the charity does not change its fundraising at all due to a larger grant, $\frac{dq_i}{dG} = \alpha \frac{-p(e)U_{cc} + (1+p(e))U_{cQ} - U_{QQ} + U_{qc} - U_{qQ}}{p(e)^2 U_{cc} - 2p(e)U_{cQ} - 2p(e)U_{cq} + 2U_{Qq} + U_{QQ} + U_{qq}}$. The awareness parameters α and β then completely determine whether direct spending or government grants crowd out or crowd in private giving more. When fundraising is responsive to direct spending and grants, the magnitudes of the fundraising effects in addition to the parameters α and β determine which type of government spending has a larger impact on private giving.

The preceding results are valid for an interior solution in which individuals contribute a positive amount to environmental quality. Bergstrom et al. (1986) consider corner solutions in their analysis and show that crowding out may be partial because non-contributors will not respond to a change in the government's provision of the public good. While contributors may decrease their contributions, the non-contributors will continue to contribute nothing. In the model presented here, allowing for non-contributors will lessen the extent of crowding out or crowding in due to the direct effect of government spending. However, if government spending reduces the cost of donating through increased fundraising, some non-contributors may begin to donate.

Despite the simplicity of this model, the implications for crowding out or crowding in of government spending are unclear. Without a price effect due to fundraising, I can find a simple condition under which both direct government spending and grants crowd out private giving, and the level of individuals' awareness about these two types of expenditures determines which effect is larger. When government spending does affect the charity's behavior through fundraising, the results are more complicated and depend on the fundraising effect. The following sections turn to an econometric model to look for evidence of crowding out or in by both direct government spending and grants using charity-level and household-level data sets.

1.3 Environmental Nonprofits Data Set

The first data set I use comes from the "NCCS-GuideStar National Nonprofit Research Database" which covers the period 1998 to 2003 and is distributed by the Urban Institute's National Center for Charitable Statistics (NCCS). The data include IRS Section 501(c)(3) nonprofit organizations that were required to file Forms 990 or 990-EZ with the IRS; these are organizations that have at least $25,000 in gross receipts and are not religious congregations. The data set contains 1,388,480 observations from public charities and is based on the tax returns filed for the fiscal years of the period. Organizations classified as 501(c)(3) private foundations, primarily those that make grants to other nonprofits, are not included in the data. Financial information from the tax returns includes amounts of direct and indirect public support, government grants, and other sources of revenue as well as various expense categories, such as fundraising.

I construct an unbalanced panel of environmental charities from the data. Nonprofit organizations in the data set are classified by the National Taxonomy of Exempt Entities (NTEE), which divides charities into 26 major groups within 10 broad categories. Nonprofits are further classified within the 10 broad categories using decile and centile codes. Environment-related charities are classified into groups C and D, or

"Environment" and "Animal-Related", respectively, in the NTEE classification scheme. Nonprofits in the Environment group are those "whose primary purpose is to preserve, protect and improve the environment." Animal-related organizations are those "whose primary purpose is to provide for the care, protection and control of wildlife and domestic animals that are a part of the living environment; to help people develop an understanding of their pets; and to train animals for purposes of showing."[7] Together, these two groups of organizations contain 12,960 charities and account for 50,758 of the observations in the data.

I follow similar steps to other researchers using NCCS data for restricting my sample and cleaning the data. First, I drop all nonprofit organizations from my sample with less than three years of observations (3,210 organizations). I also drop organization that report zero donations for all years for which they are in the sample (429 organizations). The data contain evidence of reporting error for some charities in that revenues and expenses listed by categories do not add up to total reported revenues and expenses. I drop observations for which the difference between the reported total amounts and the disaggregated amounts of revenue and expenses is greater than 1% of the reported amounts (about 24% of the observations). Because I am focusing on the effects of state spending, I further restrict my sample by excluding nonprofits that are international, national, or regional in scope (620 organizations), leaving organizations that operate at the state or local level. I also exclude support organizations, whose purpose is to provide research, fundraising, and technical assistance to other nonprofits,

[7] Definitions of NTEE categories and groups can be found in the "NTEE-CC Manual & Training Guide" available on the NCCS website: http://nccs.urban.org/.

as well as organizations located outside the 48 contiguous states (1,251 organizations).[8] The final sample contains 23,014 observations for 4,657 organizations.

Table 1.1: Summary Statistics for NCCS data

Variable	Mean ($1000s)	Standard Deviation ($1000s)	Median ($1000s)	75th percentile ($1000s)
Private Donations	424.37	2,053.40	88.02	253.26
Government Grants	114.93	802.64	0	18.96
Program Service Revenue	191.47	1,257.30	12.57	86.16
Other Revenue	142.56	1,103.17	18.85	64.83
Fundraising Expenditures	35.65	151.92	0.28	13.47

Number of organizations: 4,657
Number of observations: 23,014

	Mean	Std. Dev.	Minimum	Maximum
Environmental Spending (per capita)	57.94	29.94	19.34	387.32

Notes: All statistics are in constant 2002 dollars.

Table 1.1 presents summary statistics for the sample. All reported amounts are in constant 2002 dollars. Private donations are the largest, on average, source of revenue and are defined as the sum of direct public support, which consists of contributions received directly from individuals and foundations, and indirect public support, which includes contributions received through federated fundraising campaigns such as the United Way. The average amount of private donations received by an organization in the sample is over $424,000. The three other categories of charities' revenue are government grants, program service revenue, and other revenue. Government grants are contributions

[8] Support organizations are those with NTEE centile codes less than 20.

from federal, state, and local governments and do not include monies received from government contracts or fees for services. The second largest, on average, source of nonprofits' revenue is program service revenue, which is comprised of revenues received through charging for the services that allowed an organization to be tax-exempt, e.g., ticket sales for a museum. This category also includes government contracts. The last revenue category, other revenue, is all other sources of revenue, including membership dues, special event revenue, and dividend and interest income. Table 1.1 also reports fundraising expenditures, which are highly variable. The average amount of fundraising expenditures for an organization in the sample is close to $36,000.

I exploit cross-state differences in environmental policy to uncover the effect of government spending on charitable giving. State level measures of environmental expenditures are necessary without extensive time-series data and are appropriate for environmental policy since state governments are charged with much of its implementation. The data on state environmental spending come from the U.S. Census Bureau's *State Government Finances* reports.[9] To measure state environmental spending, I sum four categories of environmental and animal-related expenditures: "Fish and Game", "Forestry", "Parks and Recreation", and "Other Natural Resources".[10] The environmental spending measure is in per capita amounts and is in constant 2002 dollars. The last row of Table 1.1 provides summary statistics for environmental expenditures for

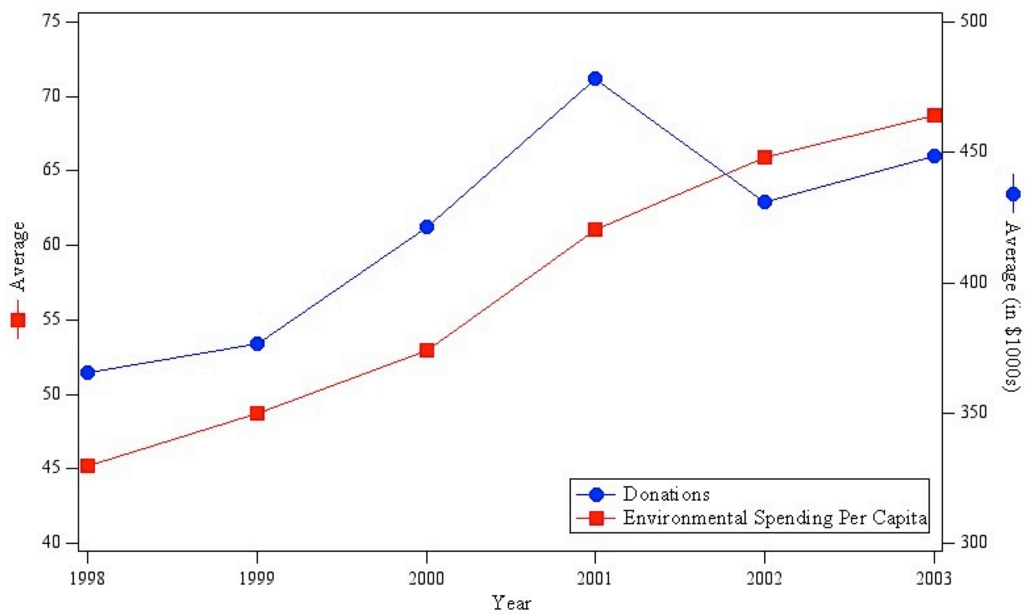
[9] Data from 1992 on are available on the U.S. Census Bureau's website.

[10] These are the same categories used by List and Sturm (2006) to measure environmental policy in their study of how electoral incentives influence secondary policy issues. See Appendix 1 for exact definitions of these categories.

the years 1998-2003 to align with the NCCS data. The average level of environmental expenditures per capita is nearly $58.

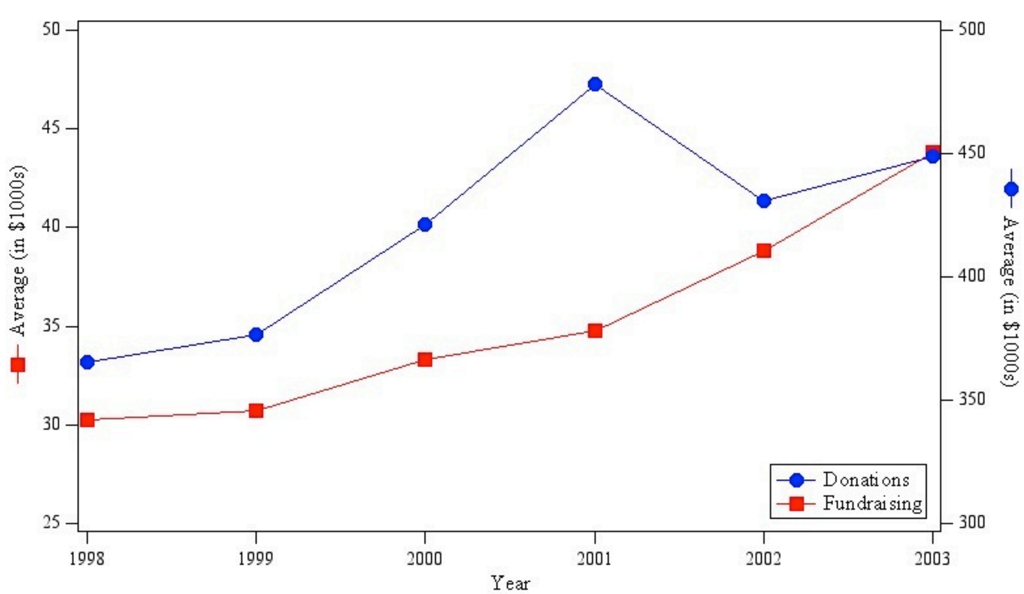
Figures 1.1 and 1.2 show the average amount of private donations received per organization per year together with average state environmental expenditures per capita and average fundraising expenditures, respectively. Private donations display a general upward trend with the exception of a dip in 2002 while both state environmental expenditures per capita and fundraising expenditures steadily increase over the sample time period. These figures indicate that private giving and government environmental expenditures may be complementary since they both generally increase over time.

Figure 1.1: Average Donations Per Organization and Average Environmental Expenditures (Per Capita)



Notes: All amounts are in constant 2002 dollars. Environmental expenditures are averaged over all states.

Figure 1.2: Average Donations and Fundraising Expenditures Per Organization



Notes: All amounts are in constant 2002 dollars.

I also collected some state-year economic and political measures to proxy for the conditions and citizens' attitudes of the states in which the nonprofits operate. The economic variables include state unemployment rate and state per capita income, available from the Bureau of Labor Statistics and Bureau of Economic Analysis, respectively. The political measures are an indicator variable for a Democratic governor, number of Democratic senators, and the fraction of total members of Congress that are Democrats. Additionally, I include state population and the fraction of the population over age 65 in the analysis. These variables may have effects on both private giving and government expenditures, and leaving them out of the analysis could lead to biased estimates. States with more liberal-leaning citizens that have a Democrat-controlled government probably spend more on environmental issues and may fund environmental nonprofits more than other states. Additionally, citizens of liberal states are more likely to donate to environmental charities.

1.4 Empirical Strategy for Nonprofits Data Set

Using the NCCS data set described above, I estimate the following empirical model:

$$Donations_{ist} = \nu_i + \psi_t + \omega EnvSpend_{st} + Controls_{ist}\delta + StateControls_{st}\tau + \varepsilon_{ist}$$

where $Donations_{ist}$ are the per capita private donations received by charity i located in state s in year t, $EnvSpend$ is per capita state environmental expenditures, $Controls$ is a vector of organization-specific control variables, and $StateControls$ is a vector of state-year controls. The organization-specific controls are fundraising expenditures and the other three categories of revenue aside from donations: government grants, program service revenue, and other revenue. The state-year controls are the economic, demographic, and political measures. Because I have a six-year panel data set, I include organization and time fixed effects in the estimation. The v_i are the organizational fixed effects that account for unobservable time-invariant heterogeneity among organizations, such as a nonprofit's reputation or quality, and the ψ_t are the year fixed effects.

I estimate the empirical equation using both ordinary least squares and instrumental variables regressions. State environmental expenditures, fundraising, and government grants are all likely to be endogenous, and ignoring this endogeneity could lead to biased estimates. For example, unobservable events could lead to an increase in the demand for a nonprofit's services so that the organization increases its fundraising efforts while private donations to the organization, government spending, and grants all simultaneously increase. In this case, not taking the endogeneity of theses variable into account would lead to upwardly biased estimates. Another possibility is that either government grants may increase while direct spending decreases or vice versa, again leading to biased estimates. Instrumental variables techniques can correct for this type of bias.

First I need instruments that help to explain state environmental expenditures but do not directly affect private giving. I use both environmental expenditures lagged by three years and an indicator for whether the state governor faces a binding term limit. State environmental policy from three years prior is unlikely to influence contemporary giving and is thus plausibly exogenous. The latter instrument is shown by List and Sturm (2006) to be significantly related to state environmental expenditures. In their study of how electoral incentives affect secondary policy issues, List and Sturm (2006) use data on environmental policy and find that politicians manipulate policy in order to attract voters. Specifically, their results show that environmental policy, measured by state environmental expenditures, differs significantly between years when the current governor can be reelected and years in which a binding term limit prevents re-election. Currently, 36 states have governor term limits in place, with most states limiting governors to two consecutive terms. It is unlikely that the occurrence of a binding term limit has a direct impact on charitable giving, and thus this instrument should also satisfy the exogeneity criterion.

I look to the literature for instruments for fundraising and government grants. Andreoni and Payne (2003, 2009) consider the issue of endogenously determined fundraising and model fundraising as an outcome of government grants and as a determinant of donations. To instrument for fundraising, they use two measures of an organization's financial security: total liabilities and total occupancy expenses. Occupancy expenses include those expenses related to an organization's use of office space or other facility. If a nonprofit is facing increased expenditures, its fundraising efforts will likely be impacted. The financial well being of an organization could affect donations, but it is unlikely that donors have contemporaneous information on an organization's financial security at the time of the donation. Instead, donors probably only have a more general sense of a charity's well being, and this is controlled for with the organization-specific fixed effects. As an instrument for government grants, I use the average grant level for the charity's state for the relevant year.

In order to evaluate the pure crowding out or crowding in effect of private giving due to government environmental expenditures, I also estimate the following equations:

$$NetDonations_{ist} = \nu_i + \psi_t + \omega EnvSpend_{st} + Controls_{ist}\delta + StateControls_{st}\tau + \varepsilon_{ist}$$

$$Fundraising_{ist} = \varphi_i + \mu_t + \theta EnvSpend_{st} + Controls_{ist}\rho + StateControls_{st}\pi + \eta_{ist}$$

where $NetDonations_{ist}$ is the amount of donations received net of fundraising costs, and $Controls_{ist}$ are the same controls specified as above without fundraising. This estimation approach is similar to the one used by Dokko (2008). Now the parameter ω captures the effect on donations, net of the cost of raising these funds, due to a change in state environmental expenditures. However, estimation of the first equation above does not decompose the effect of environmental expenditures on donations and fundraising separately, and it is unknown how much of the impact on net donations is due to a charity's fundraising response. Therefore, I also model fundraising as an outcome and estimate the direct effect of state environmental expenditures on fundraising costs, as specified in the second equation above. Here again, I use instrumental variables to correct for the endogeneity of environmental expenditures and government grants in the estimation.

1.5 Results for Nonprofits Data Set

Table 1.2 reports the results from the fixed effects regression estimates of the determinants of private donations. Column (1) shows OLS estimates without instrumental variables, and columns (1) – (6) report fixed effects instrumental variables estimates. Each specification includes the organization-level variables, state-level economic, demographic, and political measures, and organization and year fixed effects. Private donations, state environmental spending, all other organization-level variables, and state income are all in per capita (by state population) terms. Therefore, the coefficient on state environmental spending represents the dollar change in per capita private donations for a for a one dollar increase in per capita environmental expenditures. Robust standard errors are reported in parentheses.

Table 1.2: Estimates of Private Donations

Dependent Variable: Private Donations	(1)	(2)	(3)	(4)	(5)	(6)
Environmental Spending	0.000365**	0.00245**	0.00148**	0.00310*		
	(0.000145)	(0.00122)	(0.000710)	(0.00158)		
Environmental Spending, lagged					0.000935	
					(0.000580)	
% change in Environmental Spending						-0.00651*
						(0.00365)
Fundraising	2.370***	-0.508	2.327***	-3.280	0.0625	6.874**
	(0.613)	(3.367)	(0.698)	(4.330)	(3.151)	(2.806)
Government Grants	-0.00359	-0.224	0.0362	0.0504	0.0192	-0.546
	(0.0163)	(0.230)	(0.0305)	(0.0367)	(0.164)	(0.390)
Program Service Revenue	-0.00699***	-0.0184	-0.0225*	-0.00633	-0.0156	-0.0401*
	(0.00227)	(0.0153)	(0.0119)	(0.0181)	(0.0142)	(0.0212)
Other Revenue	-0.0236	0.0329	0.0591*	0.00185	0.0382	0.111**
	(0.0447)	(0.0456)	(0.0355)	(0.0610)	(0.0418)	(0.0508)
Population	-0.000539**	-0.000650**	-0.000475***	-0.000804**	-0.000705**	0.000172
	(0.000253)	(0.000269)	(0.000149)	(0.000369)	(0.000315)	(0.000412)
Fraction Population over 65	0.00246	-0.00166	-0.00238	-0.00332	-0.000338	-0.0118
	(0.00485)	(0.00823)	(0.00735)	(0.00926)	(0.00786)	(0.0112)
Income	-0.00349**	-0.00863*	-0.00568*	-0.0107*	-0.00398	-0.00205
	(0.00143)	(0.00446)	(0.00291)	(0.00548)	(0.00266)	(0.00251)
Unemployment Rate	-0.00237	-0.00415	-0.00153	-0.00485	-0.00441	-0.0265*
	(0.00172)	(0.00339)	(0.00253)	(0.00383)	(0.00347)	(0.0152)
# Democratic Senators	0.00111	0.000007	0.000889	-0.00193	-0.000979	-0.00619
	(0.00119)	(0.00272)	(0.00206)	(0.00328)	(0.00265)	(0.00585)
Fraction Democrats in Congress	-0.000276*	-0.000648*	-0.000453**	-0.000795*	-0.000242	0.00138
	(0.000160)	(0.000335)	(0.000229)	(0.000431)	(0.000193)	(0.000862)
Democratic Governor	0.000218	0.00239	0.000571	0.00304	0.00283	0.0125
	(0.00180)	(0.00377)	(0.00307)	(0.00393)	(0.00387)	(0.00937)
F-test on instruments for environmental		34.74	45.21	22.53	109.55	12.07
spending in first stage regression[a]		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
F-test on instruments for fundraising in		6.19		3.87	4.97	6.52
first stage regression[b]		(0.0001)		(0.0038)	(0.000)	(0.0000)
F-test on instruments for government		2.56			2.36	2.51
grants in first stage regression[c]		(0.0364)			(0.0377)	(0.0396)
Hansen's J statistic		1.522	2.107	5.752	5.985	0.652
(p-value)		0.217	0.147	0.0564	0.0502	0.419
Number of organizations	4657	4657	4657	4657	4657	4657
Observations	23014	23014	23014	23014	23014	23014

Notes: Column (1) reports OLS estimates, and Columns (2) - (6) report instrumental variables estimates. All regressions include organization and year fixed effects. Environmental spending, private donations, all other organization level variables, and state income are in per capita terms. Population is in 100,000s, and state per capita income is in $1000s. P-values are reported in parentheses under F statistics. Robust standard errors are reported in parentheses elsewhere.

[a] Instruments for environmental spending are an indicator for whether the state governor faces a binding term limit and environmental spending lagged by three years.

[b] Instruments for fundraising are total liabilities of the organization and occupancy expenses.

[c] Instruments for government grants are average grants to all organizations within a state for the relevant year.

*** p<0.01, ** p<0.05, * p<0.1

The first four columns of Table 1.2 all indicate that state environmental spending has a small, positive but significant effect on private donations. Without instrumenting for any of the potentially endogenous regressors, as shown in column (1), the estimated effect of a one dollar increase in state per capita environmental expenditures is about a 0.037 cent increase in per capita private donations for an environmental nonprofit. Using the mean across all nonprofits, his represents an increase of about 0.6%, and for an organization in an average sized state, this effect is equal to an increase in donations of about $4,000.[11] Fundraising also has a positive and significant effect on private donations, while the effect of government grants is negative but insignificant. Program service revenue, state population, and state income per capita all have negative and significant impacts on private donations.

Columns (2) through (6) present results for various instrumental variables specifications. For these regressions, I also report the F-statistics for each set of instruments in the first-stage regression and Hansen's J-statistic for overidentification. In all cases, the instruments for state environmental spending and fundraising are highly significant; the instruments for government grants are all also significant at the 5% level. The null hypothesis for Hansen's overidentification test is that the instruments are valid, so a rejection of this hypothesis could bring the validity of the instruments into question. For all the specifications, the null hypothesis of instrument validity cannot be rejected, although the p-values associated with this test are close to 0.05 in columns (3) and (4).

[11] The mean level of per capita donations to environmental charities is $0.062, and the standard deviation is $0.240.

Column (2) presents regression results for the complete instrumental variables model, where each of the endogenous variables (environmental spending, fundraising, and government grants) is instrumented. Column (3) presents results where only environmental spending is instrumented, and column (4) shows results after instrumenting for both environmental spending and fundraising. Again, the coefficient on state environmental spending is positive, but larger than in the OLS approach, indicating that the OLS approaches understates the effect of environmental spending. These specifications indicate that the effect of a one dollar increase in per capita state environmental spending is an increase in per capita private donations by between 0.148 and 0.31 cents. That is, on average, an environmental nonprofit with the mean level of private donations will see its per capita private donations increase by about 2.4% to 5%. For an organization in a state with the sample average population of 11.3 million, this represents an increase in private donations by about $17,000 to $35,000. After instrumenting for fundraising, its effect on private donations is negative but no longer significant. Program service revenue and state per capita income also become less significant in these specifications.

In case timing is problematic so that individuals and nonprofits are not aware of contemporaneous state environmental spending, I include a specification that incorporates lagged values for state environmental expenditures and its instruments. The estimates for this specification are reported in column (5). The coefficient on environmental spending is still positive but no longer significant, indicating that only current environmental policy affects private giving. Column (6) reports estimates for the effect of the percent change in state environmental expenditures on private donations. The coefficient on the percent change in environmental spending is negative but only significant at the 10% level. Fundraising in this specification is again significant and positive.

Table 1.3: Estimates of Private Donations with Categories of Environmental Spending

Dependent Variable: Private Donations	(1)	(2)	(3)	(4)
Fish and Game Spending	0.00177			
	(0.00192)			
Forestry Spending		0.00569		
		(0.00638)		
Other Natural Resources Spending			-0.0181	
			(0.0314)	
Parks and Recreation Spending				0.0351*
				(0.0200)
Fundraising	0.465	7.955*	25.54*	-1.855
	(3.212)	(4.654)	(15.44)	(4.635)
Government Grants	-0.476	0.0345	0.394	-0.297
	(0.374)	(0.147)	(0.577)	(0.222)
Program Service Revenue	-0.758***	-0.112	-0.437	0.106
	(0.250)	(0.388)	(0.681)	(0.412)
Other Revenue	-0.106*	0.712***	0.962	-0.0145
	(0.0549)	(0.136)	(1.250)	(0.114)
Population	-0.000399**	-0.00142	0.00221	0.00120
	(0.000157)	(0.00266)	(0.00314)	(0.00113)
Fraction Population over 65	0.0117**	0.0856	-0.0319	0.0245
	(0.00593)	(0.0654)	(0.0663)	(0.0408)
Income	-0.000552	0.0257	0.0128	-0.0859*
	(0.00241)	(0.0187)	(0.0224)	(0.0519)
Unemployment Rate	-0.00550	-0.0243	0.00167	-0.0211
	(0.00336)	(0.0235)	(0.0226)	(0.0199)
# Democratic Senators	0.00130	0.0286	0.0312	0.0343
	(0.00289)	(0.0260)	(0.0346)	(0.0296)
Fraction Democrats in Congress	0.000019	-0.000279	0.00152	-0.00412
	(0.000189)	(0.00126)	(0.00182)	(0.00275)
Democratic Governor	0.00234	-0.0486	-0.0183	-0.0403*
	(0.00357)	(0.0437)	(0.0575)	(0.0235)
F-test on instruments for environmental	17.31	2.72	15.08	2.7
spending category in first stage regression[a]	(0.000)	(0.0201)	(0.000)	(0.0196)
F-test on instruments for fundraising in	2.32	2.32	3.83	0.99
first stage regression[b]	(0.0411)	(0.0438)	(0.0018)	(0.4250)
F-test on instruments for government	4.98	1.12	2.30	2.32
grants in first stage regression[c]	(0.0001)	(0.3497)	(0.0422	(0.0410)
Hansen's J statistic	2.677	6.305	0.155	1.556
(p-value)	0.262	0.0427	0.926	0.459
Number of organizations	2047	81	1341	423
Observations	10125	396	6597	2146

Notes: All regressions include organization and year fixed effects. The four categories of environmental spending, private donations, all other organization level variables, and state income are in per capita terms. Population is in 100,000s, and state per capita income is in $1000s. P-values are reported in parentheses under F statistics. Robust standard errors are reported in parentheses elsewhere.

[a] Instruments for environmental spending categories are an indicator for whether the state governor faces a binding term limit and environmental spending lagged by three years.

[b] Instruments for fundraising are total liabilities of the organization and occupancy expenses.

[c] Instruments for government grants are average grants to all organizations within a state for the relevant year.

*** p<0.01, ** p<0.05, * p<0.1

Table 1.3 presents results for disaggregated categories of state spending. Instead of using total per capital environmental spending as in the estimates above, here I estimate separately the effect of each component of the environmental expenditure variable: fish and game, forestry, other natural resources, and parks and recreation. For each of theses types of spending, I regress private per capita donations on the spending category and same set of additional regressors used earlier. For each regression, I only use the subset of environmental nonprofits whose purpose most aligns with the relevant category of spending. For example, the regression with other natural resources spending in column (3) only uses nonprofits which are classified by NTEE codes C30, C32, and C34, which are "Natural Resources Conservation and Protection", "Water Resources, Wetlands Conservation, and Management", and "Land Resources Conservation", respectively.[12] In all specifications, the environmental spending category, fundraising, and government grants are instrumented using the same instruments as before. Here the instruments are not as significant in the first-stage regressions, so the *F*-statistics are lower, especially for fundraising and government grants. Additionally, the overidentification test hypothesis is rejected in column (4), which is not too surprising since the sample is limited to only 396 observations for 81 forestry-related organizations.

Fish and game make up the biggest category of nonprofits with 2047 organizations and over 10,000 observations. Other natural resources is also a large category with 1341 organizations and nearly 6600 observations. Fish and game and forestry spending both have positive but insignificant effects on private donations, and

[12] See Appendix 1 for a complete list of the nonprofits matched to each category of environmental spending.

parks and recreation also has a positive effect that is significant only at the 10% level. The coefficient on other natural resources is negative but insignificant. Overall, these results seem to support the earlier evidence that state environmental spending has a small, positive impact on private donations.

Next, in order to determine the impact of state environmental spending on nonprofits' fundraising expenditures and isolate any indirect effect on giving, I estimate fundraising as the outcome. By also regressing private donations net of fundraising expenditures on environmental spending, I am able to uncover the direct impact of environmental policy on giving.[13] Table 1.4 displays the estimates for the determinants of fundraising, in column (1), and net donations, reported in column (2). As before, both regressions instrument for environmental spending and government grants. The effect of environmental spending on fundraising is highly significant and positive, with a dollar increase in per capita state environmental spending increasing per capita fundraising expenditures by about 0.05 cents, which represents an increase of about 9% from the mean level of fundraising per capita.[14] Government grants have a negative and significant effect on fundraising while a number of other variables are also significant predictors of fundraising.

[13] Using Dokko's (2008) interpretation, the coefficient estimate on environmental spending represents the effect of environmental spending on the last dollar donated after controlling for the effects of fundraising. This interpretation hinges on the assumption that nonprofits fundraise up to the point where an additional dollar of fundraising generates an additional dollar in donations. If instead a dollar of fundraising brings in more than a dollar in donations, then the coefficient on environmental spending represents an upper bound (in absolute value) on the pure crowding out or crowding in effect of government spending.

[14] The mean amount of fundraising expenditures per capita is \$0.0053 with a standard deviation of \$0.028.

Table 1.4: Determinants of Fundraising and Net Donations

	(1) Fundraising	(2) Net Donations
Environmental Spending	0.000473***	0.00198**
	(0.000112)	(0.000781)
Government Grants	-0.0706**	-0.135
	(0.0295)	(0.319)
Program Service Revenue	0.00357	-0.0214*
	(0.00294)	(0.0126)
Other Revenue	-0.0147**	0.0473
	(0.00603)	(0.0351)
Population	-0.000047*	-0.000557***
	(0.000025)	(0.000176)
Fraction Population over 65	0.000712	-0.00186
	(0.000743)	(0.00772)
Income	-0.00108***	-0.00718**
	(0.000379)	(0.00308)
Unemployment Rate	-0.000863**	-0.00293
	(0.000338)	(0.00292)
# Democratic Senators	-0.000256	0.000577
	(0.000323)	(0.00213)
Fraction Democrats in Congress	-0.000094**	-0.000552**
	(0.000038)	(0.000256)
Democratic Governor	0.000636*	0.00154
	(0.000356)	(0.00302)
F-test on instruments for environmental	46.71	46.08
spending in first stage regression[a]	(0.000)	(0.000)
F-test on instruments for government	2.71	2.33
grants in first stage regression[b]	(0.0435)	(0.0719)
Hansen's J statistic	0.0176	1.603
(p-value)	0.894	0.205
Number of organizations	4657	4657
Observations	23014	23014

Notes: All regressions include organizations and year fixed effects. Fundraising, net donations, environmental spending, and all other organization level variables are in per capita terms. Population is in 100,000s, and state per capita income is in $1000s. P-values are reported in parentheses under F statistics. Robust standard errors are reported in parentheses elsewhere.

[a] Instruments for environmental spending are an indicator for whether the state governor faces a binding term limit and environmental spending lagged by three years.

[b] Instruments for government grants are average grants to all organizations within a state for the relevant year.

*** p<0.01, ** p<0.05, * p<0.1

In column (2), the estimated effect of environmental spending on donations net of fundraising is 0.198 cents. That is, a dollar increase in per capita state environmental expenditures increases net donations for a nonprofit in an average sized state by about $22,000, and is an increase of about 3.5% of the mean level.[15] This estimated effect is smaller than the estimated effect of environmental spending in column (2) of Table 1.2. Environmental spending has an indirect effect on private donation via increased fundraising, and therefore the direct effect on private donations as estimated in Table 1.4 is smaller after the effect due to fundraising is taken into account. Here, government grants have a negative but insignificant effect on net donations. Using some rough estimates of the number of local environmental nonprofits in a state, the 0.198 cent crowding in effect translates to about 30 cents in overall additional net donations per dollar increase in environmental spending. That is, the crowding in effect is about 30%. If nonprofits are able to generate more than one dollar in donations per dollar spent on fundraising, then 30% represents an upper bound on the size of the crowding in effect.

The regression results reported in Tables 1.2 – 1.4 include organizational fixed effects. Specifications without organizational fixed effects yield fairly similar results, also indicating that environmental spending and private giving have a positive and significant relationship. In those results, the coefficients on environmental spending are slightly larger and also more significant.

Overall, the results indicate that state environmental spending has a positive impact on private donation to environmental nonprofits. That is, environmental policy

[15] The mean amount of net donations per capita is $0.057 with a standard deviation of $0.228.

crowds in rather than crowds out private giving. Both the OLS and instrumental variables approaches find evidence of crowding in, but the OLS approach understates the amount of crowding in. A possible reason for the crowding in effect is that state environmental policy serves to highlight environmental issues of which either the average citizen is not aware or does not realize the importance. Then an increase in government environmental spending could influence citizens to donate more to environmental causes. Environmental nonprofits may respond to increased state spending by increasing their fundraising efforts for similar reasons. Government policy that draws attention to certain environmental issues could buoy the interests of nonprofits in these causes and lead to increased private donations via fundraising. Next I consider the impact of environmental policy from another angle, using data on the philanthropic behavior of individuals.

1.6 Household Charitable Donations and the Environment

The second data set I use is the Center on Philanthropy Panel Study (COPPS) module from the 2003, 2005, and 2007 waves of the Panel Study of Income Dynamics (PSID). Since 2001, the COPPS module has collected data on volunteering and charitable giving by households for various causes. Starting in the 2003 wave of the survey, data on the amounts of giving to environmental causes is included.[16] Because the PSID contains information on a respondent's state of residence, I can match the data on state environmental spending to the PSID data and estimate the effect of state spending

[16] The relevant survey question is "Did you or anyone in your family make donations to organizations that preserve the environment? Such as for conservation efforts, animal protection or parks?"

on giving to the environment at the household level. Additionally, the PSID contains extensive information on income, making it possible to compute marginal tax rates, which are an important determinant of charitable giving.

The 2003, 2005, and 2007 waves of the PSID data contain 24,113 observations for 10,134 families. I restrict my sample by excluding farmers and the self-employed, whose marginal tax rates are difficult to calculate, and limit my analysis to the 48 contiguous states, leaving 21,398 observations. Because an income tax deduction is allowed for charitable donations for taxpayers who itemize their returns, the price of giving is different for itemizers and non-itemizers and depends on a family's marginal tax rate. The PSID data does not report marginal tax rates, but a question is included in the survey asking if families itemize deductions on their tax returns. By using itemization status and other income information available in the data, I am able to compute marginal tax rates for each family using the NBER's TAXSIM calculator.[17] Instead of using actual marginal tax rates, which are endogenously determined by the total amount of charitable donations, I use the "first dollar" tax rate, which is the marginal tax rate for the first dollar donated.

[17] The NBER's TAXSIM program is available at http://www.nber.org/~taxsim.

Table 1.5: Summary Statistics for PSID

Variable	Mean	Std. Deviation	Minimum	Maximum
Age of Head	49.06	17.36	16	101
Married	0.49	0.50	0	1
Number of Kids	0.61	1.02	0	8
Head's Education	12.95	2.86	0	17
Male Head	0.69	0.46	0	1
White Head	0.78	0.42	0	1
Itemization Status	0.39	0.49	0	1
Donate to Charity	0.66	0.47	0	1
Family Income	56,253	57,177	-69,080	1,949,587
Price of Giving	0.82	0.25	0.06	1
Environmental Spending (per capita)	91.03	68.27	22.73	545.38

number of observations: 21,398

Notes: All statistics are weighted using PSID family weights, and all dollar values are deflated to constant 2002 dollars using the CPI.

Summary statistics for the sample are displayed in Table 1.5. The statistics are weighted using PSID family weights, and all dollar values are deflated to constant 2002 dollars using the CPI. Demographic variables included in the analysis are the head of the household's age, gender, race, marital status, and years of education, the number of kids under age 18, and family income. Average income in the sample is $56,253, and 39% of families itemized deductions. The mean price of giving, equal to one minus the marginal tax rate for itemizers, is 0.82. In the sample, 66% of households donated to charity, and of those households who donated, about 11% donated to environmental causes. The average amount of state environmental expenditures per capita across the three years of data is $91.03.

Table 1.6 displays statistics on overall donations and donations to environmental causes. The first two columns present statistics for the entire sample, and the last three columns show statistics for the average amounts of total donations, environmental donations, and percentage share of environmental donations, conditional on each variable being positive. Conditional on donating, the mean amount of total donations is about \$1774, and conditional on donating to environmental causes, the average environmental gift is about \$163. Of families who donate to the environment, the mean share of those donations out of the total amount donated is nearly 14%.

Table 1.6: Statistics on Giving

Variable	Mean	Std. Deviation	E(D|D>0)	Std. Deviation	Observations
total donations	1139.97	2658.74	1773.82	3142.50	11,859
environmental donations	12.72	121.37	162.78	405.18	1316
% environmental donations	1.07	6.56	13.76	19.54	1316

To estimate the impact of state environmental expenditures on private giving, I estimate the following equation:

$$\ln(EnvDon_{ist}) = \beta \ln(EnvSpend_{st}) + \gamma \ln(Price_{it}) + \lambda \ln(Income_{it}) + Dem_{it}\delta + \varepsilon_{ist}$$

where $EnvDon_{ist}$ is the amount of charitable donations given to environmental causes by family i living in state s in year t, $EnvSpend_{st}$ is per capita state environmental expenditures for state s in year t, and $Income_{it}$ is total family income. The price of giving, $Price_{it}$, is equal to one minus the marginal tax rate for itemizers and equal to one for non-itemizers. Demographic controls, denoted by Dem_{it}, included in the estimation are the household head's age, gender, marital status, race, education, and number of kids.

Because many families do not contribute to environmental organizations so that $EnvDon_{ist} = 0$, I follow the common solution for modeling charitable giving and estimate the above equation using a Tobit regression, which accounts for the censoring of donations at zero. Since ln(0) is undefined, I use the common practice of adding $10 to both environmental donations and income.

The PSID survey asks families about total donations to environmental causes and does not make a distinction between donations made to national and local organizations. I include year fixed effects in the estimation to account for unmeasured national factors that might influence environmental charitable giving regardless of the state of residence. Additionally, state environmental policy could affect overall donations to the environment, not only giving to local nonprofits.

As with the nonprofit-level data, I use instrumental variables to account for the endogeneity of state environmental expenditures. Unobserved events could lead individuals in a given state to donate more to environmental causes while simultaneously causing state spending to increase or decrease. I use the same instruments described in the previous section, environmental spending lagged by three years and an indicator for whether the governor of family's i's state faces a binding term limit.

1.7 Results for Household Charitable Donations

Table 1.7 reports the Tobit regression estimates for the PSID sample where the dependent variable is the natural log of donations to environmental causes. The three years of the sample are pooled for the estimation, and standard errors are clustered by families. The reported estimates are the marginal effects conditional on environmental donations being positive. State Environmental spending per capita, price, and income are also in logs, so that the coefficients represent elasticities. All specifications include year fixed effects, and all columns except for column (3) incorporate state fixed effects.

Column (1) presents result without controlling for the endogeneity of state environmental spending. The estimated coefficient on environmental spending is 0.103, meaning that a 1% increase in state environmental spending per capita increases individual environmental donations by 0.1%, on average. While small, this estimate is significant at the 5% level. Price and income are also highly significant and have the expected signs. All the other covariates are also significant. Households with heads who are married, older, and white with more education give more to the environment, while households with male heads with a greater number of kids under the age of 18 give less to environmental causes, on average.

Table 1.7: Tobit Estimates of Environmental Donations

Dependent Variable: Env. Donations	(1)	(2)	(3)	(4)	(5)
Env. Spending Per Capita	0.103**	0.159	0.111***		
	(0.0446)	(0.127)	(0.0240)		
Env. Spending Per Capita, lagged				0.0401	
				(0.196)	
% change in Env. Spending Per Capita					0.00646*
					(0.00348)
Price	-0.115***	-0.116***	-0.118***	-0.117***	-0.116***
	(0.0237)	(0.0239)	(0.0232)	(0.0241)	(0.0239)
Family Income	0.107***	0.108***	0.132***	0.109***	0.108***
	(0.0147)	(0.0149)	(0.0162)	(0.0150)	(0.0149)
Married	0.0567**	0.0572**	0.0411	0.0578**	0.0568**
	(0.0269)	(0.0272)	(0.0298)	(0.0274)	(0.0272)
Age	0.00310***	0.00313***	0.00349***	0.00315***	0.00313***
	(0.000570)	(0.000579)	(0.000632)	(0.000584)	(0.000580)
Kids	-0.0341***	-0.0344***	-0.0353***	-0.0348***	-0.0344***
	(0.00945)	(0.00950)	(0.0103)	(0.00959)	(0.00950)
Male	-0.100***	-0.101***	-0.103***	-0.102***	-0.101***
	(0.0291)	(0.0294)	(0.0322)	(0.0296)	(0.0294)
White	0.254***	0.256***	0.281***	0.259***	0.256***
	(0.0228)	(0.0228)	(0.0229)	(0.0230)	(0.0229)
Education	0.0389***	0.0393***	0.0432***	0.0393***	0.0393***
	(0.00423)	(0.00430)	(0.00470)	(0.00434)	(0.00429)
state fixed effects?	Yes	Yes	No	Yes	Yes
instrument for env. spending?	No	Yes	Yes	Yes	Yes
Chi-squared test on instruments in		1472.22	73005.12	1537.93	428.09
first stage regression		(0.000)	(0.000)	(0.000)	(0.000)
Observations	20074	20074	20074	20074	20074

Notes: Robust standard errors are reported in parentheses. Reported estimates are mariginal effects conditional on environmental donations > 0. Environmental donations, environmental spending per capita, price, and family income are in logs. All specifications include year fixed effects. P-values are reported in parentheses under the chi-squared test statistics.
*** p<0.01, ** p<0.05, * p<0.1

Column (2) reports estimates for the determinants of environmental donations after instrumenting for per capita state environmental spending. The estimated effect of environmental spending is positive and slightly larger than the estimated effect in column (1), and it is no longer significant. The χ^2 test statistic for the joint significances of the instruments for environmental spending in the first stage regression is reported near the bottom of Table 1.7 for column (2) as well as for the remaining columns, which also employ instrumental variables. In all cases, the instruments are highly significant in the first stage regressions. The specification in column (3) does not include state fixed effects; in this case, the coefficient on environmental spending is similar in magnitude to the estimates in columns (1) and (2), which includes state fixed effects, but is highly significant. Column (4) reports estimates using lagged environmental spending in case of a timing issue. In this case, the estimated effect of environmental spending is smaller and insignificant, indicating that any impact of environmental spending occurs contemporaneously. Lastly, column (5) shows estimates using the percent change in environmental spending from the previous year. The coefficient of interest is positive and significant at the 10% level. With a value of 0.00646, it represents a 0.646% increase in environmental donations for a one percentage point increase in the change in per capita environmental spending.

Table 1.8: Tobit Estimates of Share Environmental Donations

Dependent Variable: % Share Env. Donations	(1)	(2)	(3)	(4)	(5)
Env. Spending Per Capita	0.647	1.674	1.152***		
	(0.461)	(1.321)	(0.238)		
Env. Spending Per Capita, lagged				-1.008	
				(1.962)	
% change in Env. Spending Per Capita					-1.008
					(1.962)
Price	-0.940***	-0.939***	-0.960***	-0.944***	-0.950***
	(0.246)	(0.244)	(0.232)	(0.245)	(0.247)
Family Income	0.904***	0.905***	1.123***	0.907***	0.912***
	(0.146)	(0.144)	(0.156)	(0.144)	(0.145)
Married	0.445	0.445	0.265	0.443	0.448
	(0.280)	(0.282)	(0.309)	(0.283)	(0.284)
Age	0.0194***	0.0194***	0.0229***	0.0194***	0.0195***
	(0.00586)	(0.00594)	(0.00645)	(0.00597)	(0.00600)
Kids	-0.391***	-0.391***	-0.409***	-0.393***	-0.395***
	(0.0998)	(0.0968)	(0.105)	(0.0973)	(0.0977)
Male	-0.971***	-0.971***	-0.979***	-0.974***	-0.978***
	(0.311)	(0.312)	(0.342)	(0.314)	(0.315)
White	2.393***	2.390***	2.715***	2.411***	2.417***
	(0.251)	(0.238)	(0.237)	(0.239)	(0.239)
Education	0.352***	0.352***	0.391***	0.354***	0.353***
	(0.0454)	(0.0419)	(0.0463)	(0.0421)	(0.0424)
state fixed effects?	Yes	Yes	No	Yes	Yes
instrument for env. spending?	No	Yes	Yes	Yes	Yes
Chi-squared test on instruments in		1412.89	69986.13	1509.11	401.72
first stage regression		(0.000)	(0.000)	(0.000)	(0.000)
Observations	19385	19385	19385	19385	19385

Notes: Robust standard errors are reported in parentheses. Reported estimates are mariginal effects conditional on environmental donations > 0. Environmental donations, environmental spending per capita, price, and family income are in logs. All specifications include year fixed effects. P-values are reported in parentheses under the chi-squared test statistics.

*** p<0.01, ** p<0.05, * p<0.1

Table 1.8 reports estimates for Tobit regressions where the dependent variable is now the percent share of a family's total donations that goes towards environmental causes. Families may respond to state environmental spending by allocating a greater or smaller share of their charitable donations to the environment, and these regressions capture that effect. These specifications use the same set of regressors as in the estimation of the level of environmental donations. As in Table 1.7, the first column of Table 1.8 reports estimates without addressing the endogeneity of state environmental spending. The effect of environmental spending is small and positive, but insignificant, with a value of 0.647. This means that a one dollar increase in state environmental spending increases the share of environmental donations by 0.00647%. The other covariates are mostly significant and have the same signs as the estimates in Table 1.7. When environmental spending is instrumented, as shown in column (2), the effect on environmental spending becomes larger but is still insignificant. The large χ^2 test statistics indicate that the instruments are again strong predictors of environmental spending. Only in column (3), which does not incorporate state fixed effects, is the coefficient on environmental spending significant. Columns (4) and (5) show results using lagged environmental spending and the percent change in environmental spending from the previous year, respectively. In both cases, the estimated effect of environmental spending is negative but insignificant.

In general, these results indicate that the effect, if any, of state environmental spending on charitable donations is small but positive. In the preferred specifications, using state fixed effects, environmental spending does not have a significant impact on donations, but the positive coefficients corroborate the results from the charity-level data. Because charitable donations in the PSID may also include donations made to national-level nonprofits, it is not too surprising that only weak evidence is found for the crowding in effect.

1.8 Conclusion

Both the government and nonprofit organizations, through the donations of individuals, are providers of environmental quality. This paper seeks to understand the relationship between the government's environmental policy and charitable giving. While a large literature exists on the crowding out of charitable donations by government grants to charities, few studies consider the impact of direct government spending. Direct spending could have a different effect on private giving than grants to charities for several reasons. First, the general public may be more aware of either direct spending, through the news media, or grants to charities, if nonprofits advertise the receipt of such grants. Second, while it seems more likely that grants to charities would crowd out charitable giving, if only through reduced fundraising, charities may not view government spending in the same way as grants. State environmental spending may be used for purposes that are different but complementary to a charity's own use of funds, or state policy could serve to buoy a nonprofit's interest in certain causes. For these reasons, it is plausible that government spending may have a different effect than grants on charitable giving and could either crowd in or crowd out private donations.

In this paper, I present a simple theoretical model to predict the effect of government expenditures on charitable giving by individuals. The predicted effect depends on the awareness level of individuals of both government spending and grants to the environmental nonprofit as well as on the nonprofit's behavioral response through fundraising. Either crowding out or crowding in of charitable giving is possible depending on these parameters.

Environmental nonprofits are different in many ways from other kinds of charities, and by focusing of them, I add to the small empirical literature on green giving. Environmental charities receive fewer government grants and rely more heavily on donations in comparison to other charities. Using both a nonprofit-level data set and a family-level data set with information on philanthropic behavior, I estimate the effect of state environmental spending on charitable donations to green nonprofits. My estimates also control for the endogeneity of state spending, which is not addressed in the earlier literature. Results from both data sets indicate that state environmental expenditures serve to increase charitable donations, and as evidenced in the charity-level data, part of this effect is due to increased fundraising by nonprofits. Overall, environmental policy and charitable giving are complementary.

From a policy standpoint, it is helpful to understand the relationship between government spending and charitable donations used for the same purpose. And it is particularly reassuring that the government's actions do not cause a decline in private giving. This is the first paper to address the impact of endogenous government policy, including both direct spending and grants, on private giving, and future studies could extend this area of research to other types of nonprofit organizations.

Chapter 2

Can Pollution Tax Rebates Protect Low-Income Families? The Effects of Relative Wage Rates

2.1 Introduction

Market-based pollution policies, such as taxes or tradable emissions permits, can efficiently address environmental problems by forcing polluters to take into account the full cost of pollution. In order to evaluate policies and determine the tradeoffs among competing goals of economic efficiency and distributional objectives, it is important to know not only the overall costs and benefits of environmental policies but also the effects they have on different people. Additionally, the distribution of the costs depends on what is done with any revenue. Emissions permits that are distributed freely to polluting firms do not generate any government revenue, but pollution taxes or auctioned permits do. The way in which the government spends this revenue or redistributes it to taxpayers helps determine the final incidence of the policy.

One of the common arguments against pollution taxes is that households with lower income tend to spend a larger fraction of their income on polluting or pollution-intensive goods, so a tax that raises the prices of polluting goods may disproportionately hurt those with low income. However, a pollution tax may affect not only output prices, but relative wage rates as well. To consider both the uses side and the sources side of income, this paper employs a new analytical general equilibrium model in the spirit of Harberger (1962) to solve for the incidence of a pollution tax when the government has a revenue neutrality requirement. Unlike the standard Harberger model with labor and capital, however, our simple model assumes two types of labor: skilled and unskilled labor. Any exogenous shock such as a change in the pollution tax can change the demand for skilled labor relative to unskilled labor, and thus can affect relative wage rates. We assume that low-income unskilled workers spend a higher fraction of income on the polluting good, and that government tries to offset this effect by using pollution tax revenue to reduce pre-existing labor taxes on low-income unskilled workers. Then we can solve for effects on each wage rate to determine the distribution of net burdens from this overall tax reform. We show that this rebate is not enough to offset higher prices for pollution-intensive goods such as gasoline, electricity, and home heating oil. Moreover, changes in factor prices can further burden low-income families.

Related to this topic is a literature on the "double dividend", the notion that an environmental tax reform can clean up the environment and generate revenue to cut pre-existing distortionary taxes. Several studies using analytical and computational general equilibrium models have studied this question about revenue-neutral environmental policy reform, but the question is about efficiency rather than distributional effects.[1] Although some of these studies solve for the change in wage rate, they do not discuss equity issues and do not report whether the real low-skilled wage rises or falls.

A few papers do consider the distributional side of an environmental tax swap, using computational models. Using data on the carbon content of different products and

[1] See Bovenberg and de Mooij (1994a, 1994b, 1998), Bovenberg and Van der Ploeg (1994), Parry (1995), Goulder (1995), Bovenberg and Goulder (1997), Parry et al (1999), and Fullerton and Metcalf (2001).

the purchases of different income groups, Metcalf (1999, 2009) shows how an environmental tax reform could be made less regressive or perhaps not regressive at all. Using both annual income and lifetime income as measures of well-being, he finds that the use of pollution tax revenue to reduce taxes for low-income households may be distributionally neutral or even slightly progressive. Burtraw, Sweeney and Walls (2009) also calculate incidence based on product price increases (without factor price changes). Dinan and Rogers (2002) use a general equilibrium model with labor and capital, but they do not show distributional effects on the sources side. They study the distributional effects of a permit system that seeks a 15% decrease in carbon emissions, where the permits are either auctioned off or given away.[2] West and Williams (2004) empirically estimate the uses-side incidence of a gasoline tax under several scenarios, one of which is using tax revenue to decrease the tax on labor. They find a gain in efficiency and a decrease in the regressivity, but the gas tax is still not progressive.[3]

To our knowledge, no paper in this literature employs analytical general equilibrium models to analyze the distributional effects on both the uses side and sources side from a revenue-neutral pollution tax, where the tax revenue is used to lower a pre-existing labor tax (such as the U.S. payroll tax). A limitation of computational models is that the specific result depends on assumptions about parameter values. In contrast, this paper finds closed-form solutions for the change in the real unskilled wage and skilled

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[2] They assume that government can use permit revenue to cut corporate taxes, to cut payroll taxes, or to give households lump-sum rebates. The last scenario is the only one that might not be regressive.

[3] Hassett et al (2009) emphasize redistribution on a lifetime basis and by region. Metcalf et al (2008) use a computational model with tax shifting to labor and capital.

wage. Since these solutions hold for any parameter values, they show general conditions under which the relative real wage ratio rises or falls. We also use plausible parameter values to calculate burdens on each type of labor.

The model here builds upon the model of Fullerton and Heutel (2007), where labor and capital are used in both sectors, and pollution is used in only one of them. They assume one representative household, so they do not distinguish different expenditure patterns, and they employ no revenue-neutral rebate.[4] As with their model, we assume two inputs into production along with pollution, and no assumptions are made about the functional form for production. Here, however, we distinguish two groups of households. Instead of using labor and capital as the production inputs, this paper uses unskilled and skilled labor, abstracting from the use of capital. Low-income unskilled workers spend a higher fraction of income on pollution-intensive goods. Thus the focus remains on real relative burdens borne by high and low wage earners, with a swap of a higher pollution tax for a lower unskilled wage tax. All of the prior general equilibrium incidence studies mentioned above consider labor to be one homogenous input.[5]

Here, we allow for two different types of labor, where the wage for skilled workers may rise or fall relative to the wage for unskilled labor. Other studies have shown the effects on rising wage inequality from various exogenous shocks. Higher

[4] Instead, they assume that the government uses pollution tax revenue to purchase the two commodities in the economy in the same proportion as do households.

[5] In these prior models, some individuals may have a larger endowment of effective labor units, but every labor unit earns the same wage rate. Therefore, individuals at all income levels with different endowments are affected the same way when the single wage rate changes in response to an environmental tax.

demand for skilled labor relative to unskilled labor may occur with changes over time in technology, trade patterns, globalization, labor force composition, and other exogenous changes.[6] Similarly, a pollution tax could increase relative demand for skilled labor and raise the equilibrium skilled wage rate, if firms substitute out of pollution and into skilled labor. Conversely, it could increase the unskilled wage rate if firms substitute more into unskilled labor. Which is more likely? These cross-price substitution parameters have never been estimated, but we suggest that any major environmental policy reform is likely to spur sophisticated abatement technologies that favor high-skilled labor.

Given the generality of our model, the pollution tax is not guaranteed to raise the price of the dirty good, or even to reduce pollution.[7] Yet such possibilities do not merely confirm the notion that "in general equilibrium, anything can happen." To avoid that trap, we carefully categorize those perverse cases and show that they require extreme parameter values that are highly unlikely. Our paper is not about perverse cases. Even without those perverse cases, however, we demonstrate multiple ways in which low-income workers might suffer despite receiving all of the tax rebate. We say nothing about whether low-income families "ought" to be protected, only whether they *can* be protected from a fall in their real net wage rate.

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[6] Several papers focus on the role of skill-biased-technical-change and the effect on relative skilled and unskilled wages, including Bound and Johnson (1992), Katz and Murphy (1991), and Berman et al. (1994). Hanson and Harrison (1999) consider trade liberalization as an explanation for rising wage inequality, and Autor et al. (2005) evaluate the effect of shifts in labor force composition.

[7] Such possibilities were shown in Bovenberg and de Mooij (1998) and in Fullerton and Heutel (2007).

We decompose the change in their real net wage into the effect on their gross wage, the effect of the tax rebate, and the effect of product prices. Both groups face higher product prices, and yet we find that the return of *all* additional pollution tax revenue just to the low-income group is still not enough to offset the effect of higher product prices on their real net wage. One reason is that burdens on the two groups exceed the pollution tax revenue (because of deadweight loss or "excess burden"). This effect is not captured in papers mentioned above that focus just on product prices and return of revenue. Moreover, we find that additional changes in relative wage rates may offset or exacerbate that burden on low-skilled workers. Based on our data, the dirty sector is low-skilled intensive, so the pollution tax reduces demand for low-skilled labor and suppresses their wage. In addition, the low-skilled wage may fall if the pollution tax induces substitution into high-skilled labor and out of low-skilled labor. Their relative wage can only rise if low-skilled labor is a good enough substitute for pollution to offset the fact that the polluting sector is low-skill intensive *and* the fact that the tax rebate is not enough to offset their disproportionate spending on the dirty good. In almost all of our numerical examples, the real net wage of low-income workers falls. Only in rare cases would the return of revenue protect low-income workers.

The next section below presents the theoretical model. Section 2.3 shows solution results and analyzes special cases in order to interpret them. Section 2.4 discusses these results and the implications. Section 2.5 undertakes a numerical calculation based on those theoretical results, and Section 2.6 concludes.

2.2 The Model

The model presented here is similar to one in Fullerton and Heutel (2007), with the addition of three features: we consider two household and labor types instead of one, we model the government's revenue neutrality condition, and we solve for the labor tax reduction that exactly rebates the extra pollution tax revenue.

One household supplies high-wage skilled labor, while the other household supplies low-wage unskilled labor. The low-income families spend a disproportionately high fraction of income on pollution-intensive products like gasoline, electricity, and heating oil (Metcalf 1999, 2009). We assume that government tries to offset their added burden on the uses side by using the extra pollution tax revenue to lessen the payroll tax, a pre-existing tax on the labor of low-wage families. The incidence of the new tax system on the sources side is characterized by the proportional changes in the two wage rates, in response to a small exogenous increase in the pollution tax.[8]

The setting for the model is a perfectly competitive two-sector economy, with production of a "clean" good, denoted by X, and a "dirty" good, denoted by Y. Skilled and unskilled labor are used to produce both goods, and pollution is also an input in the dirty sector. The outputs are taxed at rates τ_X and τ_Y, so the prices faced by consumers

[8] We started this model with one type of labor and one type of capital, just as in Fullerton and Heutel (2007) and many other papers back to Harberger (1962), but we soon realized that those two factors do not clearly delineate who has high income or low income. The ratio of capital income to labor income plotted against total income reveals a U-shaped pattern, primarily because low-income retirees may have no labor income. A lifecycle model is way beyond the scope of this paper. Instead, the two types of labor in this paper clearly identify who has high income or low income. Skilled labor differs from unskilled labor, the ratio of their use may differ by industry, and either one might be a better substitute for pollution.

are $p_X(1+\tau_X)$ and $p_Y(1+\tau_Y)$, respectively. The constant returns to scale production functions are $X=X(L_X, H_X)$ and $Y=X(L_Y, H_Y, Z)$, where L is low-skilled labor with wage w, H is high-skilled labor with wage h, and Z is pollution. The use of pollution is also taxed, so the price of pollution is simply its tax rate, τ_Z.[9] Both types of labor are mobile between the two sectors, with fixed total amounts of each ($\overline{L}$ and $\overline{H}$). Resource constraints for these two inputs are $L_X + L_Y = \overline{L}$ and $H_X + H_Y = \overline{H}$. Totally differentiating the resources constraints yields

$$\hat{H}_X \lambda_{HX} + \hat{H}_Y \lambda_{HY} = 0 \tag{1}$$

$$\hat{L}_X \lambda_{LX} + \hat{L}_Y \lambda_{LY} = 0 \tag{2}$$

where a hat indicates a proportional change ($\hat{H}_X = dH_X/H_X$), and λ_{ij} is sector j's share of input i (e.g., $\lambda_{HX} = H_X/\overline{H}$).

Producers of X can substitute between skilled and unskilled labor according to an elasticity of substitution, σ_X. Rearranging the definition of σ_X provides a behavioral equation describing how producers of X respond to any change in input prices, p_L and p_H, namely $\hat{H}_X - \hat{L}_X = \sigma_X(\hat{p}_L - \hat{p}_H)$. These two input prices are the costs that producers face and are gross-of-tax, so $p_L = w(1+\tau_L)$ and $p_H = h(1+\tau_H)$. We assume that the increased pollution tax τ_Z generates revenue used to lower τ_L, the wage tax on low-skilled labor. For simplicity, all other tax rates are assumed to stay constant (τ_X, τ_Y, and τ_H). Thus, the proportional change in the price of low-skilled labor is $\hat{p}_L = \hat{w} + \hat{\tau}_L$

[9] The pollution tax rate, τ_Z, is a per unit tax, whereas τ_X and τ_Y are *ad valorem* tax rates.

where $\hat{w} \equiv dw/w$, but where we define $\hat{\tau}_L$ as $d\tau_L/(1+\tau_L)$. Since τ_H does not change, $\hat{p}_H = \hat{h}$. Thus we have:

$$\hat{H}_X - \hat{L}_X = \sigma_X(\hat{w} + \hat{\tau}_L - \hat{h}). \tag{3}$$

Because the dirty sector uses three factors of production, it has slightly more complicated responses. The firms' input demands are functions of input prices and output. Following Mieszkowski (1972), differentiate these demand functions to get:

$$\begin{aligned}
\hat{H}_Y &= a_{HH}\hat{p}_H + a_{HL}\hat{p}_L + a_{HZ}\hat{p}_Z + \hat{Y} \\
\hat{L}_Y &= a_{LH}\hat{p}_H + a_{LL}\hat{p}_L + a_{LZ}\hat{p}_Z + \hat{Y} \\
\hat{Z} &= a_{ZH}\hat{p}_H + a_{ZL}\hat{p}_L + a_{ZZ}\hat{p}_Z + \hat{Y}
\end{aligned}$$

where a_{ij} is the elasticity of demand for factor *i* with respect to the price of factor *j*. Then $a_{ij} = e_{ij}\theta_{Yj}$, where e_{ij} is the Allen elasticity of substitution between inputs *i* and *j* (Allen, 1938), which is negative when the two inputs are complements and positive for substitutes. Also, θ_{Yj} is the share of sales revenue from Y that is used to purchase factor *j* (e.g., $\theta_{YH} = h(1+\tau_H)H_Y/p_Y Y$). In the case where a tax per unit of pollution is the only price of pollution, then $p_Z = \tau_Z$ and $\hat{p}_Z = \hat{\tau}_Z$ (where $\hat{p}_Z \equiv dp_Z/p_Z$ and $\hat{\tau}_Z \equiv d\tau_Z/\tau_Z$). Substitute the Allen elasticities and the proportional price changes into the differentiated factor demands above, and subtract the third equation from the first two:

$$\hat{H}_Y - \hat{Z} = \theta_{YH}(e_{HH} - e_{ZH})\hat{h} + \theta_{YL}(e_{HL} - e_{ZL})(\hat{w} + \hat{\tau}_L) + \theta_{YZ}(e_{HZ} - e_{ZZ})\hat{\tau}_Z \tag{4}$$

$$\hat{L}_Y - \hat{Z} = \theta_{YH}(e_{LH} - e_{ZH})\hat{h} + \theta_{YL}(e_{LL} - e_{ZL})(\hat{w} + \hat{\tau}_L) + \theta_{YZ}(e_{LZ} - e_{ZZ})\hat{\tau}_Z \tag{5}$$

These two equations represent how producers of Y react to changes in prices and tax rates that are attributable to an exogenous increase in the pollution tax, τ_Z.

The perfect competition and constant returns to scale assumptions imply that sales revenue in each sector equals the sum of payments to factors of production. Differentiating these conditions, we have:

$$\hat{X} + \hat{p}_X = \theta_{XH}(\hat{h} + \hat{H}_X) + \theta_{XL}(\hat{w} + \hat{\tau}_L + \hat{L}_X) \tag{6}$$

$$\hat{Y} + \hat{p}_Y = \theta_{YH}(\hat{h} + \hat{H}_Y) + \theta_{YL}(\hat{w} + \hat{\tau}_L + \hat{L}_Y) + \theta_{YZ}(\hat{\tau}_Z + \hat{Z}). \tag{7}$$

Then, using the perfect competition assumption, differentiate each sector's production function to describe how output quantities change with inputs:

$$\hat{X} = \theta_{XH}\hat{H}_X + \theta_{XL}\hat{L}_X \tag{8}$$

$$\hat{Y} = \theta_{YH}\hat{H}_Y + \theta_{YL}\hat{L}_Y + \theta_{YZ}\hat{Z}. \tag{9}$$

In order to discuss the distribution of net burdens in the simplest possible way, we assume that the economy has two types of consumers, low-skilled and high-skilled laborers, where subscripts L and H denote these groups (e.g. X_L is the amount of good X consumed by low-skilled workers). These two groups may spend on X and Y in different proportions, but they have the same elasticity of substitution in utility, σ_U, between X and Y. This simplifying assumption makes the model easier to solve, and yet does not detract from the purpose of the paper to find effects on these two groups. The elasticity of substitution has major impacts on economic efficiency, but it has only second-order effects on burdens. The first-order impact of $\hat{p}_X$ and $\hat{p}_Y$ on the relative burden of each group is the major pre-existing difference in the fraction of income that each group spends on Y. Rearranging the definition of σ_U yields behavioral equations that show how the two consumers' demands respond to changes in output prices:

$$\hat{X}_L - \hat{Y}_L = \sigma_U(\hat{p}_Y - \hat{p}_X) \tag{10}$$

$$\hat{X}_H - \hat{Y}_H = \sigma_U(\hat{p}_Y - \hat{p}_X) \tag{11}$$

The two goods are purchased by both types of workers. The total quantity of good X can then be expressed as $X = X_L + X_H$, and similarly $Y = Y_L + Y_H$. Differentiating these equations yields:

$$\hat{X} = \hat{X}_L \frac{X_L}{X} + \hat{X}_H \frac{X_H}{X} \tag{12}$$

$$\hat{Y} = \hat{Y}_L \frac{Y_L}{Y} + \hat{Y}_H \frac{Y_H}{Y}. \tag{13}$$

The government budget constraint requires a fixed amount, G, matched by tax revenue:

$$G = \tau_Z Z + h\tau_H H + w\tau_L L + p_Y \tau_Y Y + p_X \tau_X X.$$

Rather than specify direct government spending on X and Y, we say that the fixed revenue G is returned to the two groups [δG to the high-income group, and $(1\text{-}\delta)G$ to the low-income group]. Since G is fixed, these lump-sum transfers are fixed and do not affect our results. Only the *increase* in pollution tax revenue is used to cut τ_L (leaving G fixed). With the revenue neutrality condition ($dG = 0$) and the assumption that only tax rates τ_Z and τ_L can change, we differentiate the government budget constraint and rearrange to solve for the proportional change in the labor tax:[10]

[10] Tax rates τ_X and τ_Y are fixed, but changes in X and Y will affect revenue.

$$\hat{\tau}_L = \frac{1}{\overline{L}p_L}[-Z\tau_Z(\hat{\tau}_Z + \hat{Z}) - \overline{H}h\tau_H\hat{h} - \tau_L\hat{w} - p_Y\tau_Y Y(\hat{p}_Y + \hat{Y}) - p_X\tau_X X(\hat{X} + \hat{p}_X)]. \qquad (14)$$

The two consumer groups allocate spending on the two goods according to their preferences and budget constraints. For example, the budget constraint for skilled labor is $p_X(1+\tau_X)X_H + p_Y(1+\tau_Y)Y_H = h(H_X + H_Y) + \delta G$. Of the two spending equations, one is independent. The second can be derived from the first, using Eqs. (6) and (7). Therefore, only one consumer group budget constraint is necessary, and differentiation of the skilled labor budget constraint yields:

$$p_X(1+\tau_X)X_H(\hat{p}_X + \hat{X}_H) + p_Y(1+\tau_Y)Y_H(\hat{p}_Y + \hat{Y}_H) = h(H_X + H_Y)\hat{h}. \qquad (15)$$

Equations (1)-(15) are fifteen linear equations in sixteen unknowns: $\hat{H}_X, \hat{H}_Y, \hat{L}_X$, $\hat{L}_Y, \hat{w}, \hat{h}, \hat{p}_X, \hat{X}, \hat{X}_L, \hat{X}_H, \hat{p}_Y, \hat{Y}, \hat{Y}_L, \hat{Y}_H, \hat{Z}$, and $\hat{\tau}_L$. Good X is chosen as numeraire, so that $\hat{p}_X = 0$. The model can be solved through successive substitution to obtain equations for each of the remaining fifteen endogenous variables in terms of exogenous parameters and the exogenous change in the pollution tax, $\hat{\tau}_Z$.

2.3 Results

The variables of most interest are the price changes, to determine the relative incidence on skilled and unskilled labor. Table 2.1 shows solutions for these selected variables and the change in pollution, $\hat{Z}$.

The expressions for $\hat{p}_H$ and $\hat{p}_L$ are "closed form" solutions, because they contain only parameters and the exogenous policy shock ($\hat{\tau}_Z$), but the expression for $\hat{w}$ contains $\hat{\tau}_L$ (which is endogenous). All of these solutions *can* be expressed just in terms of exogenous parameters and $\hat{\tau}_Z$, but that would make the expressions much longer. For example, a closed-form solution for $\hat{Z}$ can be obtained by substituting expressions for $\hat{h}$ and $\hat{w}+\hat{\tau}_L$ into the $\hat{Z}$ expression shown in Table 2.1, and that $\hat{Z}$ can be used to obtain closed-form expressions for $\hat{\tau}_L$ and $\hat{w}$.

Table 2.1: Proportional changes in prices, wage rates, and amount of pollution

$$\hat{h} = \hat{p}_H = \frac{\theta_{XL}\theta_{YZ}}{D}[A(e_{HZ} - e_{ZZ}) - B(e_{LZ} - e_{ZZ}) - (\gamma_H - \gamma_L)(\sigma_U N + J)]\hat{\tau}_Z \tag{16a}$$

$$\hat{w} = \hat{p}_L - \hat{\tau}_L = \frac{\theta_{XH}\theta_{YZ}}{D}[A(e_{ZZ} - e_{HZ}) - B(e_{ZZ} - e_{LZ}) + (\gamma_H - \gamma_L)(\sigma_U N + J)]\hat{\tau}_Z - \hat{\tau}_L \tag{16b}$$

$$\hat{p}_Y = \frac{(\theta_{YL}\theta_{XH} - \theta_{YH}\theta_{XL})}{D}\theta_{YZ}[A(e_{ZZ} - e_{HZ}) - B(e_{ZZ} - e_{LZ}) + (\gamma_H - \gamma_L)(\sigma_U N + J)]\hat{\tau}_Z + \theta_{YZ}\hat{\tau}_Z \tag{16c}$$

$$\begin{aligned}\hat{Z} = -\frac{1}{C}[[\theta_{YH}[\beta_H(e_{HH} - e_{ZH}) + \beta_L(e_{LH} - e_{ZH}) + \sigma_U N + J] - \frac{1}{C_H}h\overline{H}(\frac{Y_H}{Y_L} - \frac{X_H}{X_L})]\hat{h} \\ + \theta_{YL}[\beta_H(e_{HL} - e_{ZL}) + \beta_L(e_{LL} - e_{ZL}) + \sigma_U N + J](\hat{w} + \hat{\tau}_L) \\ + \theta_{YZ}[\beta_H(e_{HZ} - e_{ZZ}) + \beta_L(e_{LZ} - e_{ZZ}) + \sigma_U N + J]\hat{\tau}_Z]\end{aligned} \tag{16d}$$

$$\begin{aligned}\hat{\tau}_L = [\frac{1+\tau_L}{\overline{L}p_L}][(-Z\tau_Z + T_X(\theta_{XH}\gamma_H + \theta_{XL}\gamma_L) - T_Y)\hat{Z} + [-Z\tau_Z + \\ T_X\theta_{YZ}(\theta_{XH}\gamma_H(e_{HZ} - e_{ZZ}) + \theta_{XL}\gamma_L(e_{LZ} - e_{ZZ})) - T_Y\theta_{YZ}(1 + \theta_{YH}(e_{HZ} - e_{ZZ}) + \theta_{YL}(e_{LZ} - e_{ZZ}))]\hat{\tau}_Z \\ +[-\overline{H}\tau_H h + M\overline{L}p_L + T_Y(F - \theta_{YH}) + (T_X\theta_{XH}\gamma_H - T_Y\theta_{YH})E_H + (T_X\theta_{XL}\gamma_L - T_Y\theta_{YL})E_L]\hat{h}]\end{aligned} \tag{16e}$$

where $\gamma_H \equiv \dfrac{\lambda_{HY}}{\lambda_{HX}} = \dfrac{H_Y}{H_X}$, $\gamma_L \equiv \dfrac{\lambda_{LY}}{\lambda_{LX}} = \dfrac{L_Y}{L_X}$, $\beta_H \equiv \frac{X}{X_L}\theta_{XH}\gamma_H + \frac{Y}{Y_L}\theta_{YH}$, $\beta_L \equiv \frac{X}{X_L}\theta_{XL}\gamma_L + \frac{Y}{Y_L}\theta_{YL}$,

$A \equiv \gamma_L\beta_H + \gamma_H(\beta_L + \frac{Y}{Y_L}\theta_{YZ})$, $B \equiv \gamma_H\beta_L + \gamma_L(\beta_H + \frac{Y}{Y_L}\theta_{YZ})$, $C \equiv \beta_H + \beta_L + \frac{Y}{Y_L}\theta_{YZ}$,

$$\begin{aligned}D \equiv C\sigma_X + A[\theta_{XH}\theta_{YL}(e_{HL} - e_{LZ}) - \theta_{XL}\theta_{XH}(e_{HH} - e_{HZ})] - B[\theta_{XH}\theta_{YL}(e_{LL} - e_{LZ}) - \theta_{XL}\theta_{YH}(e_{HL} - e_{HZ})] \\ - (\gamma_H - \gamma_L)(\sigma_U N + J)(\theta_{XH}\theta_{YL} - \theta_{XL}\theta_{YH}) - (\gamma_H - \gamma_L)\frac{1}{C_H}h\overline{H}(\frac{Y_H}{Y_L} - \frac{X_H}{X_L})\end{aligned}$$

$T_X \equiv p_X\tau_X X$, $T_Y \equiv p_Y\tau_Y Y$, $F \equiv \dfrac{\theta_{YL}\theta_{XH}}{\theta_{XL}}$, $M \equiv \dfrac{\tau_L}{1+\tau_L}\dfrac{\theta_{XH}}{\theta_{XL}}$,

$E_H \equiv \theta_{YH}(e_{HH} - e_{ZH}) - \dfrac{\theta_{YL}\theta_{XH}}{\theta_{XL}}(e_{HL} - e_{ZL})$, $E_L \equiv \theta_{YH}(e_{LH} - e_{ZH}) - \dfrac{\theta_{YL}\theta_{XH}}{\theta_{XL}}(e_{LL} - e_{ZL})$

$N \equiv \dfrac{X}{X_L} + (1-\alpha_H)(\dfrac{Y_H}{Y_L} - \dfrac{X_H}{X_L})$, $J \equiv \alpha_H(\dfrac{Y_H}{Y_L} - \dfrac{X_H}{X_L})$

$C_H \equiv p_X(1+\tau_X)X_H + p_Y(1+\tau_Y)Y_H$, and $\alpha_H \equiv \dfrac{p_Y(1+\tau_Y)Y_H}{p_X(1+\tau_X)X_H + p_Y(1+\tau_Y)Y_H}$

For further simplification, parameters are combined into definitions. That is, γ_H and γ_L are relative factor intensities. Our data below indicate that $\gamma_L > \gamma_H$, so the dirty sector is low-skilled labor intensive (or, equivalently, the clean sector uses skilled labor intensively). The constants A and B are difficult to interpret, but they are weights on the terms involving the Allen elasticities (e_{ij}). In equations (16), these terms represent "substitution effects" and indicate how producers of Y substitute among inputs when pollution becomes more expensive. The constant C partly determines the change in pollution ($\hat{Z}$) in (16d). The constants A, B, and C are all positive, but the denominator D cannot be signed in general. Constants T_X and T_Y represent tax payments received by the government on the two goods prior to the pollution tax increase, and these help to determine the magnitude of the decrease in the unskilled labor tax rate. The E constants that appear in the solution for $\hat{\tau}_L$ help determine how the substitution effects impact the magnitude of $\hat{\tau}_L$. The terms N and J summarize the relative consumption of the two goods by the two consumer groups. While N can be shown to be positive, the sign of J is ambiguous without additional assumptions (discussed below).[11]

Two effects appear in (16a), (16b), and (16c) that are comparable to effects identified by Mieszkowski (1967) and discussed by Fullerton and Heutel (2007). First, the "substitution effect" is the term $[A(e_{HZ} - e_{ZZ}) - B(e_{LZ} - e_{ZZ})]$. Through this term, the higher pollution tax ($\hat{\tau}_Z > 0$) tends to help high-skilled labor ($\hat{h} > 0$) whenever e_{HZ} is larger than e_{LZ}, that is, when H is a better substitute for pollution than is L. Second, the "output effect" is represented here by the term $(\gamma_H - \gamma_L)(\sigma_U N + J)$. If low-skilled

[11] By rearranging terms, $N = (x_L + \alpha_H x_H)/x_L + (1-\alpha_H)y_L/y_H$ where both terms are positive.

labor is used more intensively in the dirty sector, then $(\gamma_H - \gamma_L) < 0$. Because σ_U and N are both positive, then the first part of this term, $(\gamma_H - \gamma_L)\sigma_U N$ is negative. A higher tax on emissions, $\hat{\tau}_Z$, reduces the dirty output in a way that depends on consumer preferences represented by σ_U, and therefore reduces demand for L relative to H (reducing w and raising h). It places more burden on the factor intensively employed in the dirty sector.

The additional term J means that this effect on factor prices also depends on the relative consumption by the two groups. For concreteness, assume that low-skilled consumers spend a greater proportion of income on the dirty good than do high-skilled consumers. In other words, assume Y_L/X_L exceeds Y_H/X_H, which makes J negative.

The additional J term does not appear in results of Fullerton and Heutel (2007) because they assume government spends the tax revenue in the same way as the one representative consumer. Here, the extra tax revenue is rebated to unskilled labor, with disproportionate spending on the dirty good, so this particular use of the revenue increases purchases of Y. This J term helps the factor used intensively in Y, offsetting the usual output effect.[12]

Because the solutions for these variables are complicated, with offsetting effects, the determination of the overall sign of each is difficult. In this most general case, the tax on pollution might even reduce the price of the dirty good, or increase the amount of pollution. Therefore, we employ special cases that simplify the expressions and allow

[12] The N and J terms show how expenditure patterns affect demands for X and Y, and thus demands for L and H, with effects on the sources side. Later, we show how different expenditures affect the uses side.

more definitive results. The rest of this section focuses on the sources side of income, and a later section focuses on the uses side.

2.3.1 Case 1: Equal Factor Intensities ($\gamma_H = \gamma_L = \gamma$)

For the first special case, suppose that the two sectors have the same ratio of high-skilled to low-skilled labor ($H_Y / H_X = L_Y / L_X$). This condition eliminates the output effect, $(\gamma_H - \gamma_L)(\sigma_U N + J)$ and leaves the sign of each price change to depend only on the substitution effects – the e_{ij} parameters. In this simple case, the solutions are:

$$\hat{p}_Y = \theta_{YZ}\hat{\tau}_Z \tag{17a}$$

$$\hat{h} = \hat{p}_H = \frac{\theta_{XL}\theta_{YZ}\gamma(e_{HZ} - e_{LZ})}{D_1}\hat{\tau}_Z \tag{17b}$$

$$\hat{w} = \hat{p}_L - \hat{\tau}_L = \frac{-\theta_{XH}\theta_{YZ}\gamma(e_{HZ} - e_{LZ})}{D_1}\hat{\tau}_Z - \hat{\tau}_L \tag{17c}$$

where $D_1 = (\sigma_X - \theta_{XL}\theta_{YH}\gamma e_{HH} - \theta_{XH}\theta_{YL}\gamma e_{LL}) + \gamma(\theta_{XL}\theta_{YH} + \theta_{XH}\theta_{YL})e_{HL}$. In this case, $\hat{p}_Y$ in (17a) is clearly positive, since θ_{YZ} is positive, and because the pollution tax is increased ($\hat{\tau}_Z > 0$). The sign of $\hat{h}$ depends on whether $e_{HZ} > e_{LZ}$ and $D_1 > 0$. To put a sign on this denominator, define

$$\text{Condition 1:} \quad e_{HL} > \frac{-\sigma_X + \theta_{XL}\theta_{YH}\gamma e_{HH} + \theta_{XH}\theta_{YL}\gamma e_{LL}}{\gamma(\theta_{XL}\theta_{YH} + \theta_{XH}\theta_{YL})}.$$

The denominator D_1 is positive if and only if Condition 1 holds. Since $e_{HH} < 0$, $e_{LL} < 0$, and all other terms are positive, the ratio on the right side of the inequality is strictly negative. For this condition to hold, it is sufficient that $e_{HL} > 0$, which means that low-skilled labor and high-skilled labor are substitutes. More generally, Condition 1 may still hold if low-skilled and high-skilled labor are not too complementary.

If that condition holds, and high-skilled labor is a better substitute for pollution than unskilled labor ($e_{HZ} > e_{LZ}$), then the pollution tax raises the high-skilled wage ($\hat{h} > 0$). If Condition 1 fails, and the two types of labor are "too" complementary, then $\hat{h}$ is negative.[13] Less unlikely is that Condition 1 holds but unskilled labor is a better substitute for pollution, where again $\hat{h}$ is negative.[14]

The sign of $\hat{w}$ depends on $\hat{\tau}_L$ and on the $\hat{p}_L$ term (with sign opposite to that of $\hat{h} = \hat{p}_H$). The extra pollution tax revenue is used to reduce the low-skilled tax, so $\hat{\tau}_L$ is negative.[15] The reduction in this tax rate has a powerful, positive impact on $\hat{w}$, since the goal of the tax swap is to raise the net wage for low-income families. If unskilled labor is a better substitute for pollution than is high-skilled labor ($e_{LZ} > e_{HZ}$), then the $\hat{p}_L$ term in (17c) is positive, as long as D_1 is positive. In that case $\hat{w}$ is unambiguously positive. The positive effect of $\hat{\tau}_L$ on $\hat{w}$ can be overwhelmed, however, if unskilled labor is enough less of a substitute for pollution ($e_{HZ} >> e_{LZ}$), so that a reduction in Z leads to a large reduction in demand for L. Then the net unskilled wage may fall.

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[13] Intuition is difficult for the perverse case where Condition 1 fails and $D_1 <0$. How could the pollution tax hurt high-skilled labor, even though H is a better substitute for pollution ($e_{HZ} > e_{LZ}$)? The higher price of pollution induces substitution into H, but if L and H are sufficiently complementary, then the firm wants to employ more L, which raises w relative to h.

[14] If *both* conditions fail, so that $D_1 < 0$ *and* $e_{HZ} < e_{LZ}$, then h would rise.

[15] We assume that the pollution tax rate is on the normal side of the Laffer curve, so that increasing the rate yields additional revenue that can be used to cut τ_L.

Table 2.2 summarizes these results and conditions.[16] In the first row of Table 2.2, $e_{HZ} < e_{LZ}$, so low-skilled labor is a better substitute for pollution, and the increased pollution tax definitely raises the net low-skilled labor wage (even before accounting for $\hat{\tau}_L < 0$).[17] In the next two rows of Table 2.2, high-skilled labor is a better substitute for pollution than low-skilled labor, a situation that tends to help high-skilled labor and reduce the low-skilled wage. In the second row, the decrease in τ_L is *not* enough to overcome this injury, so the net-of-tax low-skilled wage falls. In the third row, however, the decrease in τ_L is large enough to offset this burden, so that the low-skilled wage rises. The intuition for the sign of $\hat{h}$ is similar and depends on whether low-skilled labor or high-skilled labor is a better substitute for pollution. Since the high-skilled labor tax rate does not change, though, any burden on the high-skilled wage cannot be offset by tax changes.

[16] The $\hat{\tau}_L$ term is endogenous. The three conditions in Table 2.2 can be expressed in terms of exogenous parameters only, but these conditions would then be extremely long and complicated.

[17] But even this case does not guarantee that L is held harmless, because this analysis does not yet account for the effect on L from spending disproportionately on Y when $\hat{p}_Y > 0$. So far, we discuss only the sources side ($\hat{w}$ and $\hat{h}$), but later we discuss effects on the two groups from the uses side ($\hat{p}_Y > 0$).

Table 2.2: Changes in *w* and *h* for the case of equal factor intensities

If high-skilled labor and unskilled labor are not too complementary	$\hat{h}$	$\hat{w}$
(1) $e_{HZ} < e_{LZ}$ (*unskilled labor is a better substitute for pollution*)	< 0	> 0
(2) $e_{HZ} > e_{LZ}$ and $\hat{\tau}_L > \dfrac{-\theta_{XH}\theta_{YZ}\gamma(e_{HZ} - e_{LZ})}{D_1}\hat{\tau}_Z$	> 0	< 0
(3) $e_{HZ} > e_{LZ}$ and $\hat{\tau}_L < \dfrac{-\theta_{XH}\theta_{YZ}\gamma(e_{HZ} - e_{LZ})}{D_1}\hat{\tau}_Z$	> 0	> 0

2.3.2 Case 2: Equal Factor Intensities and $e_{HZ} = e_{LZ}$

This case is a special version of Case 1 with equal factor intensities ($\gamma_H = \gamma_L = \gamma$), with the additional requirement that low-skilled labor and high-skilled labor are equally substitutable for pollution. In this most simple case, the solutions are now just:

$$\hat{p}_Y = \theta_{YZ}\hat{\tau}_Z > 0 \tag{18a}$$

$$\hat{w} = -\hat{\tau}_L > 0 \tag{18b}$$

$$\hat{h} = 0 \tag{18c}$$

The change in the price of Y is the same as in Case 1 and is positive. Whereas equal factor intensities removes the output effect, setting $e_{HZ} = e_{LZ}$ removes the substitution effect. Now relative wage rates do not change at all ($\hat{p}_L = \hat{p}_H = 0$), but pollution tax revenue is used to cut the low-skilled labor tax ($\hat{\tau}_L < 0$, so $\hat{w} > 0$). These simplifying assumptions remove factor price effects and leave only the product price effects analyzed by Metcalf (1999, 2009) and Burtraw et al (2009). The remaining question, analyzed below, is whether the rebate is enough to overcome the burden from $\hat{p}_Y > 0$.

2.3.3. Case 3: Fixed Input Proportions ($e_{ij} = 0$)

In this case, all the elasticities are set to zero, so that the substitution effects disappear, and only the output effects remain. Now results are driven by whether sector Y is high-skilled labor intensive or low-skilled labor intensive. The solutions are:

$$\hat{p}_Y = \frac{[C\sigma_X - (\gamma_H - \gamma_L)\frac{1}{C_H} h\overline{H}(\frac{Y_H}{Y_L} - \frac{X_H}{X_L})]\theta_{YZ}}{D_3}\hat{\tau}_Z \tag{19a}$$

$$\hat{h} = \hat{p}_H = -\frac{\theta_{XL}\theta_{YZ}(\gamma_H - \gamma_L)(\sigma_U N + J)}{D_3}\hat{\tau}_Z \tag{19b}$$

$$\hat{w} = \hat{p}_L - \hat{\tau}_L = \frac{\theta_{XH}\theta_{YZ}(\gamma_H - \gamma_L)(\sigma_U N + J)}{D_3}\hat{\tau}_Z - \hat{\tau}_L \tag{19c}$$

where $D_3 = C\sigma_X - (\gamma_H - \gamma_L)(\sigma_U N + J)(\theta_{XH}\theta_{YL} - \theta_{XL}\theta_{YH}) - (\gamma_H - \gamma_L)\frac{1}{C_H} h\overline{H}(\frac{Y_H}{Y_L} - \frac{X_H}{X_L})$.

The denominator D_3 can be positive or negative, depending on whether the dirty sector is low-skilled or high-skilled labor intensive, as well as on other parameters. Even with the removal of the substitution effects, the results are still complicated and difficult to sign. An additional simplification is that the elasticity of substitution in consumption between X and Y, σ_U, is equal to unity (the value used in the numerical section of Fullerton and Heutel, 2007). This simplifying assumption means that the term $(\sigma_U N + J)$ is now unambiguously positive, and it allows us to sign the results based on factor intensities in the dirty industry and several other conditions. Appendix 2 contains a diagram of these sub-cases and shows the signs of $\hat{p}_Y$, $\hat{h}$, and $\hat{w}$.

When the dirty sector is high-skilled intensive ($\gamma_H > \gamma_L$), the results are definitive: p_Y increases, h decreases, and w increases. These results are consistent with the intuition stated earlier that the output effect places more of the burden on the factor used intensively in the dirty sector. When the dirty industry is low-skilled intensive ($\gamma_H < \gamma_L$), the situation is more complicated. In this case, unskilled labor might be hurt despite their tax cut. Also, the dirty good's price could actually decrease. When the industries have very different factor intensities, so that γ_L is much larger than γ_H, then w likely decreases. The output effect hurts intensively-used unskilled labor, which can overtake the opposing decrease in the tax on unskilled labor. A full categorization of results for Case 3 is provided in Figure 2.1 of Appendix 2.

2.4 Effects on the Uses Side

Thus far, we have only discussed the effect that a pollution tax swap has on the sources side of income for both types of workers. We next consider the uses side and changes in the real net unskilled wage. Define $\omega \equiv p_L(1-\tau_L)/p_Q^L = w/p_Q^L$, where p_Q^L is a price index, $p_Q^L \equiv \alpha_L p_Y(1+\tau_Y) + (1-\alpha_L) p_X(1+\tau_X)$.[18] Differentiation yields $\hat{p}_Q^L = \alpha_L \hat{p}_Y$. We then calculate the change in the real net unskilled wage:

$$\hat{\omega} = \hat{p}_L - \hat{\tau}_L - \hat{p}_Q^L. \tag{20}$$

This equation nicely decomposes the effect on the real net wage into three components: the change in the gross wage, the change in the tax rate, and the change from product prices. Similarly, define the real net wage for skilled labor as $\psi \equiv p_H(1-\tau_H)/p_Q^H$ $= h/p_Q^H$, with analogous definitions of p_Q^H and α_H. Since τ_H is fixed, we have:

$$\hat{\psi} = \hat{p}_H - \hat{p}_Q^H. \tag{21}$$

In Case 1 with equal factor intensities, we show above that $\hat{p}_Y > 0$, so $\hat{w}$ may be positive or negative. Thus $\hat{\omega}$ is definitely negative when $\hat{w} < 0$; in particular, when high-skilled and unskilled labor are not too complementary, and low-skilled labor is highly complementary with pollution, then the real unskilled wage falls. For $\hat{w} > 0$, it is more likely that the real net wage increases if α_L is small, that is, if unskilled laborers do not spend too disproportionately on good *Y*. Case 2 simplifies the analysis even more, with the additional assumption that high-skilled labor and unskilled labor are equally substitutable for pollution. In this case $\hat{p}_Y > 0$, and the real wage increases if $-\hat{\tau}_L > \alpha_L \hat{p}_Y$. Thus, if the wage tax cut is very large, or if unskilled workers do not spend too much on *Y*, then their real wage is likely to rise.

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[18] The weight α_L is unskilled labor's share of expenditures on Y (using initial values, so α_L is a fixed parameter). Thus, $\alpha_L \equiv p_Y(1+\tau_Y)Y_L/[p_X(1+\tau_X)X_L + p_Y(1+\tau_Y)Y_L]$. Below we set initial prices to 1.0 and output tax rates to zero, so we have $\alpha_L \equiv Y_L/(Y_L + X_L)$.

Case 3 is unique because $\hat{p}_Y$ may be positive or negative. Therefore, $\hat{\omega}$ is definitely positive when $\hat{w} > 0$ and $\hat{p}_Y < 0$. Otherwise, as before, $\hat{\omega}$ may still be positive as long as unskilled labor's expenditure share on Y is not too large. It is also possible that $\hat{\omega} > 0$ in the perverse case where both the net wage and p_Y fall.

We now summarize all our analytical results. Ignoring unlikely perverse cases where p_Y may fall or Z may rise, we have identified several reasons that the real net wage of low-income workers (ω) may fall, even when pollution tax revenue is used to cut their labor tax rate. First, ω may fall if H is better than L as a substitute for pollution. Second, ω may fall if the dirty sector is low-skill intensive. Third, ω may fall if low-skill labor spends disproportionately on the dirty good.

2.5 Numerical Analysis

Because the general model's results are complicated and difficult to sign, we now assign plausible parameter values and solve numerically for changes in wage rates and other variables. We then can change certain parameter values, in a sensitivity analysis, to see if and when extreme parameter values generate perverse results. This section provides only an illustration of plausible magnitudes in the analytical model, however, not a fully detailed numerical simulation of the pollution tax reform (particularly since we omit capital and changes in returns to capital).

We use several data sources. First, we define the "dirty" sector as the fourteen most polluting industries using data from the EPA's Toxic Release Inventory (TRI) for

2006. The "clean" sector then includes all other industries.[19] The TRI contains information on nearly 650 chemical releases for various kinds of manufacturing, electric utilities, and metal and coal mining. We use this information along with data from the Occupational Employment Statistics (OES) survey from 2007 in order to identify factor income shares for each sector.[20] The OES has data on employment and average wages for each of over 800 occupations, grouped by NAICS industry code. We classify skilled labor as occupations with mean annual wage of at least $50,000. Adding total compensation to workers in the clean sector implies that the clean sector represents about 93% of income.[21] The share of the clean sector's compensation to low-skilled workers is about 54%, and the share of the dirty sector's compensation to low-skilled workers is about 64%, indicating that the dirty sector is indeed low-skilled labor-intensive.

[19] No industry is perfectly "clean", especially when considering intermediate inputs that are ignored here. We simply separate the dirtiest 14 from other industries. These initial steps follow Fullerton and Heutel (2007), but here we use more recent data. TRI industry data use 3 and 4-digit NAICS codes. Aggregating to the 3-digit level, the industries we put in the "dirty" sector are those with the most on- and off-site disposal of monitored chemicals: mining, utilities, chemical manufacturing, primary metals, paper manufacturing, waste management, food manufacturing, beverage and tobacco manufacturing, petroleum and coal product manufacturing, fabricated metals, transport equipment, plastics and rubber manufacturing, nonmetallic mineral products manufacturing, and wood products manufacturing. The "clean" sector is comprised of the remaining 75 industries. This data set is available at http://www.epa.gov/triexplorer/industry.htm.

[20] The Occupational Employment Statistics survey is available from the Bureau of Labor Statistics' website: http://www.bls.gov/data.

[21] For each industry, we multiply employment in each skilled occupation by the mean annual wage for that occupation, and sum over all skilled occupations to calculate total compensation to skilled labor. Similarly, for unskilled labor, we take employment in each occupation times the mean wage for each, and sum.

This information allows us to specify that $\theta_{XL} = 0.54$ and $\theta_{XH} = 0.46$ in the clean sector. In the dirty sector, however, we do not have data on the fraction of sales revenue attributable to pollution, so we cannot yet determine all factor shares. Following Fullerton and Heutel (2007), we choose $\theta_{YZ} = 0.25$. The remaining 75% of sales revenue is paid to labor, of which 64% is to low-skilled labor (so $\theta_{YL} = 0.48$), and the remainder to high-skilled labor (so $\theta_{YH} = 0.27$). We define a unit of each input or output so that all initial prices are one ($w = h = p_Z = p_X = p_Y = 1$). Also, perfect competition implies zero profits, so $X = (1 + \tau_H)H_X + (1 + \tau_L)L_X$ and $Y = (1 + \tau_H)H_Y + (1 + \tau_L)L_Y + Z$. Defining total factor income to equal one as well means that $(1 + \tau_X)X + (1 + \tau_Y)Y = 1$. Using all these relationships, we can then solve for all the initial factor allocations and parameters shown in the top portion of Table 2.3.

Table 2.3: Summary of parameters

H_Y	$= 0.017$	L_Y	$= 0.029$
H_X	$= 0.301$	L_X	$= 0.459$
θ_{Y_H}	$= 0.317$	θ_{YL}	$= 0.433$
θ_{XH}	$= 0.455$	θ_{XL}	$= 0.545$
λ_{HY}	$= 0.052$	λ_{LY}	$= 0.059$
λ_{HX}	$= 0.948$	λ_{LX}	$= 0.941$
γ_H	$= 0.055$	γ_L	$= 0.063$
$\tau_H = 0.4$, $\tau_L = 0.1$			
$\tau_X = 0$, $\tau_Y = 0$, $\tau_Z = 1$			
$\alpha_H = 0.05$, $\alpha_L = 0.12$, $\delta = .39$			

We also need numerical values for the tax rates (τ_X, τ_Y, τ_H, and τ_L), expenditure shares (α_H and α_L), the fraction of initial tax revenue returned to high-skilled labor (δ), and elasticities. We choose zero for the tax rates on *X* and *Y*, 10% as the tax rate on unskilled labor, and 40% as the tax rate on skilled labor.[22]

We approximate the expenditure shares for each group of workers using data on income quintiles from the 2007 Consumer Expenditure Survey (CEX). The bottom three quintiles correspond to our low-skilled workers, with average pre-tax incomes of $10,531, $27,674, and $46,213 respectively. The top two quintiles, representing high-skilled workers, have mean incomes of $72,460 and $158,388. We add up expenditure per quintile on natural gas, electricity, fuel oil, and gasoline in order to obtain an approximation of the fraction of income spent on the "dirty" good.[23] This yields α_L = 12% (so 0.88 is the fraction spent on the clean good by low-skilled workers) and α_H = 5% (so 0.95 is the fraction spent on the clean good by high-skilled workers). We assume that initial government revenue is simply distributed in proportion to each group's initial income, so $\delta = 39\%$.

We use an elasticity of substitution in production for the clean sector of one, and an elasticity of substitution in utility of one (following Fullerton and Heutel, 2007). No

[22] Excise and other output taxes in the two sectors are similar to each and do not add much to the model, so we choose the simplest case where the tax rates on *X* and *Y* are both zero. Labor tax rates of 10% and 40% for unskilled and skilled labor, respectively, approximate payroll and income taxes for the two groups.

[23] Our dirty industries include mining, chemicals, and primary metals, but these outputs are not purchased directly by consumers and so do not appear in the CEX. The most pollution-intensive consumer goods categories are natural gas, electricity, fuel oil, and gasoline. Consumer expenditure for these four categories is about 6.8%, which is close to our definition of the dirty sector (representing 7% of income).

study has estimated which factors of production are better substitutes for pollution, especially for our two factors (high-skilled and low-skilled labor). The point here is to see how much these Allen cross-price elasticities matter, so we use values ranging from –1 to 1. These then determine the own-price elasticities. We are now able to solve for the relevant magnitudes in changes from the initial equilibrium, as shown in Table 2.4.

Table 2.4: A 10% Increase in the Pollution Tax (% changes)

Row	(1) e_{HZ}	(2) e_{LZ}	(3) Pollution $\hat{Z}$	(4) Low-Skill Wage $\hat{w}$	(5) High-Skill Wage $\hat{h}$	(6) Price of Dirty Good $\hat{p}_Y$
1	1	-0.5	-3.932	0.173	0.124	2.494
2	0	0	-2.932	0.285	0.012	2.499
3	0.5	0	-4.567	0.195	0.048	2.498
4	1	0	-6.190	0.105	0.083	2.496
5	-0.5	0.5	-3.488	0.311	-0.065	2.503
6	0	0.5	-5.148	0.219	-0.029	2.501
7	0.5	0.5	-6.797	0.128	0.007	2.500
8	1	0.5	-8.433	0.038	0.043	2.498
9	-0.5	1	-5.676	0.246	-0.106	2.505
10	0	1	-7.350	0.154	-0.069	2.503
11	0.5	1	-9.012	0.062	-0.033	2.501

Table 2.4 shows results for the relevant changes of interest, assuming that the pollution tax rate increases by 10%. The different rows show results when the elasticities e_{HZ} and e_{LZ} are varied, while e_{HL} is held constant at a value of one (so skilled and unskilled labor are substitutes).[24] For all of the combinations of parameters shown in the

[24] We also tried $e_{HL} = e_{HZ} = e_{LZ} = 1$, where the implied own-price elasticities are: $e_{HH} = –2.2$, $e_{LL} = –1.2$, and $e_{ZZ} = –3$. These elasticity value are not "perverse", but they do not result in positive additional revenue, violating our assumption that the pollution tax rate is on the normal side of the Laffer curve.

table, the increase in the pollution tax always reduces the amount of pollution ($\hat{Z} < 0$) and increases the price of the dirty good ($\hat{p}_Y > 0$).

In all rows, the output effect dampens the unskilled wage, since the dirty sector is L-intensive. The net wage for unskilled workers (w) always rises, however, because it includes the rebate of pollution tax revenues through the reduction in τ_L. The overall changes in w are quite small, ranging from about 0.04% to 0.31%. This net wage rises most when the substitution effect favors low-skilled labor, that is, when L is a better substitute for pollution (when $e_{LZ} > e_{HZ}$, as in rows 5 and 9). The price of the dirty good rises, however, so the effect on the *real* net wage is not yet clear.

In Table 2.4, the changes for the high-skilled wage ($\hat{h}$) are positive or negative, but small in magnitude. Through the substitution effect, the higher pollution tax tends to raise the high-skilled wage ($\hat{h}$>0) whenever $e_{HZ} > e_{LZ}$ (high-skilled labor is a better substitute for pollution than is unskilled labor, as in rows 1, 3, 4, and 8). When $e_{LZ} > e_{HZ}$, however, the high-skilled wage falls (in rows 5, 6, 9, 10, and 11).

While changes in both real net wage rates may be small, the taxed sector is only 7% of national income. The nationwide wage rates are driven primarily by the clean sector, which employs 93% of labor. Thus, even a 10% higher pollution tax has only small effect on w relative to h. As shown in Case 2 above, the tax has *no* effect on *relative* wage rates when factor intensities are the same in the two sectors and substitution parameters are equal ($e_{HZ} = e_{LZ}$). The extra pollution tax also collects only a small amount of revenue. Indeed, the tax must be small for our linear approximations to be valid. The fact that the tax is small, however, does not detract from our ability to address the question in this paper, namely whether the rebate of all extra revenue is enough to make up for higher product prices and for changes in factor prices. The answer to that question is based on our decomposition of all effects on each real net wage rate.

We undertake that decomposition in Table 2.5, where the rows correspond exactly to the rows of Table 2.4, as indicated by e_{LZ} and e_{HZ} in the first two columns. Then column (3) shows just the effect on the gross nominal wage p_L, which already includes both the output effect and the substitution effect. The output effect always acts to reduce the low-skilled wage, because the dirty sector is low-skilled labor intensive. The substitution effect exacerbates that output effect when $e_{LZ} < e_{HZ}$ (as in the first row), and it offsets the output effect when $e_{LZ} > e_{HZ}$ (as in rows 5, 6, 9, 10, and 11).

Table 2.5: A Decomposition of Effects from Factor Prices, Rebates, and Product Prices

Row	(1) e_{HZ}	(2) e_{LZ}	(3) Factor Price $\hat{p}_L$	(4) Tax Rebate $-\hat{\tau}_L$	(5) Product Prices $-\hat{p}_Q^L$	(6) Real Net Wage $=\hat{\omega}$	(7) Factor Price $\hat{p}_H$	(8) Product Prices $-\hat{p}_Q^H$	(9) Real Net Wage $=\hat{\psi}$
1	1	-0.5	-0.103	0.277	-0.299	-0.126	0.124	-0.125	-0.001
2	0	0	-0.010	0.295	-0.300	-0.015	0.012	-0.125	-0.113
3	0.5	0	-0.040	0.235	-0.300	-0.105	0.048	-0.125	-0.077
4	1	0	-0.069	0.175	-0.300	-0.194	0.083	-0.125	-0.042
5	-0.5	0.5	0.054	0.257	-0.300	0.011	-0.065	-0.125	-0.190
6	0	0.5	0.024	0.195	-0.300	-0.081	-0.029	-0.125	-0.154
7	0.5	0.5	-0.006	0.134	-0.300	-0.172	0.007	-0.125	-0.118
8	1	0.5	-0.036	0.074	-0.300	-0.262	0.043	-0.125	-0.082
9	-0.5	1	0.088	0.158	-0.301	-0.054	-0.106	-0.125	-0.231
10	0	1	0.058	0.096	-0.300	-0.147	-0.069	-0.125	-0.194
11	0.5	1	0.028	0.034	-0.300	-0.238	-0.033	-0.125	-0.158

The real net wage change is $\hat{\omega} = \hat{p}_L - \hat{\tau}_L - \hat{p}_Q^L$ for low-skill labor, $\hat{\psi} = \hat{p}_H - \hat{p}_Q^H$ for high-skill labor.

Column (4) shows the effect of the tax rebate, τ_L, which always helps low-skilled labor. Interestingly, the amount of that rebate varies, because it depends on the amount of revenue from the pollution tax. That pollution tax revenue is small when pollution abatement is relatively easy, so the rebate is small when *both* types of labor are good substitutes for pollution (rows 8 and 11). The final component is the effect of product prices, p_Q^L, in column (5), which always reduces the *real* net wage. These three components add to the total effect on the real net wage ω in column (6).

The real net wage falls in almost every case ($\hat{\omega} < 0$, where $\hat{\omega} = \hat{p}_L - \hat{\tau}_L - \hat{p}_Q^L$). It rises slightly in row 5 only, where low-skilled labor is much better than high-skilled labor as a substitute for pollution ($e_{LZ} > e_{HZ}$). This result answers the key question of our paper: only under special conditions can the rebate of revenue to the low-income group necessarily protect them against a loss in real income.

An estimated distribution of elasticities in Table 2.5 could be used in a Monte Carlo simulation to calculate the expected change in the real net wage ω. Without such estimates, we cannot state the probability of each row in Table 2.5. Yet the table makes clear that Monte Carlo simulations are not necessary. Any feasible set of probability weights for the rows of Table 2.5 could only yield an expected fall in the real net wage.

Importantly, the decomposition allows us to address *why* the real net wage falls. Notice first that the effect of the rebate is relatively large. In this model, however, the tax rebate in column (4) is *never* enough to offset the effect of product prices in column (5). This result seems somewhat remarkable, since the pollution tax places some burden on high-skilled labor as well as on low-skilled labor, and yet all of the pollution tax revenue is given as a rebate just to low-skilled labor! Why? In this general equilibrium model, because of "excess burden", consumers lose more than the revenue from the tax, especially in the cases where abatement is easy (where e_{LZ} and e_{HZ} are both positive, and revenue is small, as in rows 8 and 11).[25]

Thus, the rebate of the entire tax is not enough to protect low-income families just from the effects of higher prices for electricity, heating fuel, and gasoline. This problem is even worse when factor prices also change to hurt low-skilled labor, especially where H is better than L as a substitute for pollution (rows 1,3, 4, 8).

In the last three columns of Table 2.5, the effect of the tax on the gross wage for high-skilled labor ($\hat{p}_H$) plus the effect from higher produce prices, ($-\hat{p}_Q^H$) add to the effect on their real net wage($\hat{\psi}$). The gross nominal wage may rise or fall, depending on elasticities, but high-skilled labor gets no rebate in this tax swap. The effect of higher prices always swamps any positive effect on the wage rate, however, so the real net wage always falls. In Table 2.5, both real net wage rates always fall (except for a tiny gain to low-skilled labor in row 5 discussed above).

So far, in all scenarios, our illustrative parameters have yielded positive values for the change in the nominal net low-skilled wage ($\hat{w} > 0$ in every row of Table 2.4). We next perform sensitivity analysis to see the effect on w with more extreme parameter values. As described in Case 1 of the previous section, whenever H and L are not "too" complementary, the denominator is positive ($D_I > 0$). Then if high-skilled labor is

[25] A general equilibrium model like ours could be used to derive and calculate excess burden, but we intentionally eschew this step to focus on distributional effects rather than efficiency effects.

a *much* better substitute for pollution, the nominal low-skilled wage may fall.[26] Here we find that if $e_{LZ} = -1$, then $\hat{w}$ is negative and $\hat{h}$ is positive whenever e_{HZ} is bigger than about 2.4 (still keeping $e_{HL} = 1$). These new parameter values are a bit different from those in Tables 2.4 and 2.5, but they generate a very different outcome.

Conversely, we also consider the case where high-skilled and low-skilled labor are highly complementary with each other. We take $e_{HL} = -5$ and then check for values of e_{HZ} and e_{LZ} where $\hat{w}$ is negative. For example, $e_{LZ} = 10$ and $e_{HZ} = 9$ is a case where $\hat{w}$ is negative, and $\hat{h}$ is positive, even though low-skilled labor is a better substitute for pollution. Other combinations of e_{HZ} and e_{LZ} also can make w fall, but their values must still be quite large.

Other extreme parameters can yield other perverse outcomes such as a decrease in the price of the dirty good or an increase in pollution. Without a comprehensive search, we were able to find one example where pollution rises ($e_{HL} = 5$, $e_{HZ} = -8$, and $e_{LZ} = 6$, which imply that $e_{HH} = -0.52$, $e_{LL} = -7.12$, and $e_{ZZ} = -0.25$). The point is certainly not that a pollution tax is likely to raise pollution. Rather, finding this one case confirms that only extreme elasticity values can generate perverse results.

The intended effect of a tax rebate for low-income workers is for their net wage not to fall relative to the high-skilled wage. However, we have identified several examples where a very different result is possible. For policy reasons, it is important to understand that any intended protection of low-skilled labor may not be realized. We have shown that even when the nominal low-skilled wage increases, low-skilled labor

[26] Our numerical example does not exactly match Case 1, however, because factor intensities are not equal.

may still bear a disproportionate share of the tax burden. Still, however, low-skilled labor in these cases could be hurt even more without the rebate.

2.6 Conclusion

In order to evaluate different policies, it is important to understand not only the efficiency costs of environmental taxes but distributional effects as well. Using pollution tax revenue to reduce pre-existing labor taxes can lessen the regressivity of the tax, and that might make a pollution tax more politically viable. While the double dividend literature has focused on the efficiency side of this kind of tax swap, this paper considers equity issues and the circumstances under which real net wages may rise or fall. The model developed here is simple but can provide key insights into the effects of a pollution tax increase and labor tax decrease on low-skilled and high-skilled workers.

Using a general equilibrium model, we derive closed-form solutions for changes in wage rates of both types of workers, the price of the dirty good, and the amount of pollution. We find perverse cases where the price of the dirty good may fall, or where pollution may rise, but these cases are unlikely and are not the point of this paper. More to the point is that even without extreme parameter values, the use of the pollution tax revenue to cut low-income workers' labor tax may not raise their real net wage. The tax cut for low-skilled workers certainly has a positive impact on the net low-skilled wage, but for three reasons this effect may not be enough to overcome the burden imposed by an increased pollution tax. First, their real net wage may fall if high-skilled labor is better as a substitute for pollution than is low-skilled labor. Second, it may fall if the dirty sector makes intensive use of low-skilled labor. And third, of course, it may fall if low-income families spend disproportionately on the dirty good.

In our numerical analysis, using reasonable parameter values, we find that the nominal net low-skilled wage increases in all cases, but low-skilled workers can still bear a disproportionate burden of the tax, due to the increase in the price of the dirty good. This numerical simulation does not provide definitive results for the incidence of this tax swap, but it does indicate what parameters need better estimation, and what values of those parameters make policy unable to offset the adverse effects of pollution taxes on low-income families.

Chapter 3

The Distributional Effects of Grandfathered Emissions Permits: A Case Study of the SO_2 Allowance Market

3.1 Introduction

Economists have long touted market-based policies as a superior solution for addressing pollution problems. As opposed to command and control methods, which dictate uniform emissions reductions or require specific emissions reducing technologies, market-based approaches such as tradable permit systems or emissions taxes allow firms to undertake the most cost-effective methods for pollution reduction. The 1990 Clean Air Act Amendments (CAAA) established a tradable permit system for SO_2 emissions; these emissions permits are handed out to electric utilities for free through "grandfathering." Yet grandfathered permit systems have a potential disadvantage that other market-based policy instruments such as auctioned permit systems or taxes do not. Because firms in a grandfathered permit system receive permits for free, their equity value is increased through the market value of the emissions permits. This increased equity value is then passed on to shareholders who predominantly belong to higher income groups, creating an unequal burden among households.

In this paper, I build upon the model of Parry (2004) to measure the household distributional effects of the SO_2 allowance market by calculating a range of possible outcomes for the incidence of permits. Parry (2004) develops a simple partial equilibrium model to calculate the combined distributional effects of grandfathered permits. Because this policy raises production costs and, in turn, the equilibrium output price, it affects consumers through their uses of income. Since it provides profits for firms, it also affects individuals through their sources of income. Parry (2004) uses stylized facts and calibration to parameterize his model, including the selection of two parameters to characterize the firm's abatement cost function. I use the general framework of Parry's (2004) model, but I replace his calibrated abatement cost function using empirical estimates from Considine and Larson (2006). By using empirical results, I can obtain better, more precise estimates of the incidence of SO_2 tradable permits.

A major advantage of using econometric estimates in an abatement cost function is that I can also use econometric estimates of the error bounds. In particular, Parry (2004) is limited to the use of one central case plus sensitivity cases where a key parameter is changed; these bounds are not well estimated. In contrast, bounds on the estimated coefficients are provided by Considine and Larson (2006). Using simple Monte Carlo techniques, I can calculate the 5th and 95th percentiles of the distribution of possible results when using all of their estimated coefficients in the Parry model.

Much of the literature on the distributional effects of environmental policies has focused on taxes or command and control regulations. In general, these policies have been found to be regressive, since low-income households spend a greater proportion of their income on goods whose prices have risen as a result of the policy.[1] More recently,

[1] See Fullerton and Heutel (2007) on a general pollution tax; Poterba (1991b), Metcalf (1999, 2009), Hasset et al (2009), and Grainger and Kolstad (2010) on carbon taxes; Walls and Hansen (1999), Mayeres (2001), and West (2004) on transportation taxes; Poterba (1991a), Casler and Rafiqui (1993), West and Williams (2004), and Bento et al

the environmental incidence literature has paid greater attention to tradable permit systems. Jorgenson et al. (1998) employ a dynamic general equilibrium model to study the distributional effects of a carbon permit trading system using simulated consumption data for infinitely lived households. Dinan and Rogers (2002) expand upon this topic using detailed micro data to study the distributional effects of a carbon allowance policy designed to achieve a 15 percent reduction in carbon emissions. They consider two possible versions of the policy: a grandfathered approach where permits are given away, and an auctioned system through which the government would retain 100 percent of the auction revenue. If the permits are given away, the government would still be able to capture some the permit value through taxes on increased profits that the permit allowances would create. They conclude that the government ultimately determines the incidence of the policy by determining how the permits will be allocated and how to use the permit rent collected. Specifically, they estimate that under grandfathered permits, households in the lowest income quintile would be about $500 worse off per year and that households in the highest quintile would be about $1000 better off due to the increased value in their stockholdings. However, under an auctioned permit system with permit revenue returned to households in equal lump-sum payments, the lowest income households would be better off by around $300 whereas the highest income households would be about $1700 worse off.

Parry (2004) continues the analysis of the distributional effects of emissions permits by considering a wider range of pollutants and comparing the burden on lower

(2009) on fuel taxes; and Gianessi et al (1979), Freeman (1979), Robinson (1985), and Fullerton and Heutel (2010) on command and control policies.

income households under emissions permits with that imposed by other types of emissions policies.[2] In his paper, Parry develops and calibrates an analytical model to calculate the distributional effects of employing grandfathered permits aimed at reducing power plant emissions of SO_2, NO_x, and carbon. Parry finds that grandfathered emissions permits for the reduction of NO_x and carbon are highly regressive, while the cap on SO_2 emissions imposed by the CAAA is also regressive, but to a lesser degree. Additionally, he finds that the burden imposed on low-income households can be smaller under other types of policies, ones that do not transfer wealth to higher income stockholders.

Parry assumes a simple functional form for the firm's abatements costs. His abatement cost function has two parameters, both of which are chosen based on stylized facts, not estimated using data. In contrast, Considine and Larson (2006) estimate a cost function using firm-level electric utility data. In their paper, Considine and Larson (2006) take into account substitution possibilities between environmental resources (emissions) and other factors of production such as labor and capital in order to estimate an empirical model consisting of factor demand equations.[3]

I use the basic framework employed by Parry, modifying it to reflect empirical estimates of substitution in the electricity industry. Through a partial equilibrium model that establishes the burden imposed by emissions permits on households, I calculate this

[2] See also Burtraw et al (2009), Slammin and Ballard (2009), Blonze et al (2010), and Rausch et el (2010) for more recent work on the distributional effects of cap-and-trade.

[3] A prior model of Carlson et al. (2000) estimates a translog cost function for electric power generation that depends on the prices for labor, capital, high and low sulfur coal, the levels of output and emissions, and a technological time trend. Considine and Larson (2006) build on this model by including emissions as a variable input and permit stocks as a quasi-fixed factor of production.

burden for different income groups, and, like Parry (2004), compare it to that caused by other policy instruments. From the demand equation for emissions estimated by Considine and Larson (2006), I compute the firm's abatement cost function and use it to replace the calibrated abatement cost function in Parry's (2004) basic model. Focusing specifically on the SO_2 permit system, I estimate the imposed burden across income groups and compare it with other pollution policies such as a tax or technology mandate. Because I use empirical results in my calculations, I am able to take advantage of the estimated error bounds and obtain a distribution of possible outcomes that reflect the underlying uncertainty. In contrast to performing sensitivity analysis where one parameter is arbitrarily varied, the range of results produced by the Monte Carlo analysis is derived by allowing all of the relevant parameters to vary simultaneously. This process produces a more realistic interval of results, and policymakers can use this better information to evaluate policy implications and make more informed policy decisions.

From these calculations, I find that the SO_2 permit system is regressive, hurting lower income households more than higher income ones. My results show that regardless of how the permit rents are recycled, the policy is highly regressive in the sense that the lowest-income households are made worse off while the highest-income households are made better off. This is in contrast to Parry (2004), who found that the policy is only "intermediate regressive": the poorest households bear a higher burden in terms of percentage of income than the richest households.

The next section below presents the analytical model of Parry (2004), and the Considine and Larson part of the model is given in Section 3.3. Calculation techniques are given in Section 3.4, and the main results are presented and discussed in Section 3.5. Section 3.6 undertakes a Monte Carlo analysis, and Section 3.7 concludes.

3.2 The Parry Model

The model presented here is adapted directly from Parry (2004), with the exception of the abatement cost function. I derive an abatement cost function using Considine and Larson's estimated output cost function and factor demand equation for emissions.

As in the Parry model, households are divided into five groups ranked according to income. The lowest quintile is group 1, which corresponds to the group with the lowest income. The highest quintile, group 5, corresponds to that group with the highest income. All households within quintile i are assumed to be identical and to consume two goods, a clean good (C_i) and a dirty good (D_i). The dirty good is a product such as electricity whose production creates polluting emissions, and the clean good can be thought of as aggregate consumption of all other non-polluting goods. The model has N households in each group, where the utility of a representative household from goup i is given as

$$U_i(C_i, D_i) \tag{1}$$

and aggregate consumption of the clean and dirty goods is

$$C = \sum_{i=1}^{5N} C_i,\ D = \sum_{i=1}^{5N} D_i \tag{2}$$

A Household of type i choose C_i and D_i to maximize utility subject to a budget constraint

$$C_i + pD_i = I_i, \tag{3}$$

where p is the price of the dirty good relative the numeraire clean good, and I_i is disposable income after pollution regulation. Disposable income, I_i, is made up of wage income (w_i), profit income from household i's stockholdings in the dirty sector (π_i), and a cash transfer from the government resulting from the recycling of pollution permit revenue (G_i). Thus $I_i = w_i + \pi_i + G_i$.

Assume demand for the dirty good is linear so that household i's demand for D_i can be approximated as

$$D_i \approx [1 + \eta_i(p - p_0)/p_0]\, D_i^0, \qquad \eta_i = \frac{dD_i}{dp}\frac{p_0}{D_i^o} < 0, \qquad D_i^0 = \frac{s_i I_i}{p_0} > 0, \tag{4}$$

where p_0 is the pre-regulation price of the dirty good, η_i is the price elasticity of demand for the dirty good, D_i^0 is the pre-regulation demand for the dirty good, and s_i is the fraction of i's budget spent on the dirty good, evaluated at p_0.

In his model, Parry assumes that firms are homogeneous and competitive, using labor to produce the two consumption goods. They reduce e (emissions per unit of D) according to the minimized abatement cost function

$$c(a) = \frac{\gamma a^\theta}{\theta}, \tag{5}$$

where a is emissions abatement per unit of output, and γ and θ are parameters, so that $c(a)$ is the abatement cost per unit of output. In my model, I replace Parry's $c(a)$ with an abatement cost function using estimates from Considine and Larson (2006), further explained below.

Continuing with Parry's model, aggregate emissions from production of the dirty good (D) are given by

$$E = eD. \tag{6}$$

Assume that implementing a tradable emissions permit system yields an equilibrium permit price of τ. The permit rents are therefore τE, of which the government may retain a fraction λ through auctioning off some or all of the permits or taxing profit income. Government revenue, R, is thus

$$R = \lambda \tau E. \tag{7}$$

The case of a fully grandfathered policy with no profit taxation implies $\lambda = 0$, so $R = 0$. A completely auctioned permit system or 100% profit taxation implies that $\lambda = 1$.

Profit income π_i is positive when permits are grandfathered (and firm profits are not taxed 100%). Assume the government transfer, G_i, resulting from the recycling of government revenue, R, can take two forms

$$G_i^{PROP} = \frac{R}{N}\frac{I_i^0}{\sum_{i=1}^{5} I_i^0}, \qquad G_i^{LST} = \frac{R}{5N} \tag{8}$$

The first form, G_i^{PROP}, corresponds to the distributionally neutral case where government revenue is returned to household i in proportion to household i's income as a share of total income, and the second form, G_i^{LST} corresponds to the progressive case where government revenue is returned to households via the same lump sum payment to each.

In an emissions permit market, firms equate their marginal costs of abatement, collectively generating an equilibrium permit price. Since firms are competitive, they pass the increased cost of producing D to consumers. This increased cost of production includes abatement costs and the opportunity cost of emissions permits. Thus, the cost of D increases by $c(a)$ and τe, where $c(a)$ denotes abatement cost. These equilibrium conditions are

$$c'(a) = \tau, \quad p = p^0 + \tau e + c(a), \quad E = eD(p), \tag{9}$$

where the superscript denotes pre-regulation.

In equilibrium, household i receives profit income

$$\pi_i = (k_i/N)(1 - \lambda)\tau E \tag{10}$$

where k_i is the fraction of all stockholdings in the dirty good industry held by households in quintile i, and $(1 - \lambda)\tau E$ is the permit rents retained by the dirty good industry. The profits from permit rents result in equity gains that are then passed to shareholders.

Define the initial burden (B_i) as the loss of consumer surplus resulting from the change in price of the dirty good. Define ΔI_i as the change in income from profits and government transfers. The net burden (NB) for household i is the difference between B_i and ΔI_i. Thus B_i and ΔI_i are expressed as

$$B_i \approx (p - p_0)D_i - \frac{1}{2}\eta_i p_0 D_i^0 \{\frac{p - p_0}{p_0}\}^2, \quad \Delta I_i = G_i + \pi_i \tag{11}$$

and the net burden is given by

$$NB_i = B_i - \Delta I_i. \tag{12}$$

3.3 The Considine and Larson Model

To be consistent with the paper by Considine and Larson (2006), this section describes their model using their own notation. Since this notation conflicts with the notation of Parry, this section is self-contained.

In the framework of Considine and Larson (2006), firms are competitive and cost-minimizing. They choose factor inputs of low sulfur fuel (x_{1t}), high sulfur fuel (x_{2t}), labor and maintenance (x_{3t}), and emissions (x_{4t}), and they have stock of emissions permits (B_t) and capital stock (K_t). They minimize the expected sum of discounted costs

$$\min E_t \sum_{t=\tau}^{\infty} R_{t,\tau}\{G(w_{1t}, w_{2t}, w_{3t}, w_{4t} \mid B_t, K_t, Y_t, Z_t) + \mu_{bt} B_t + \mu_{kt} K_t + c_k(I_\tau) + c_b(N_\tau)\} \qquad (13)$$

where $R_{t,\tau}$ is a discount factor applied at time t for costs accruing at time τ, the w_{it}'s are input prices, Y_t is output, Z_t is a time trend representing technological change, and μ_{bt} and μ_{kt} are user costs for permit stocks and capital. Additionally, this model assumes that changes in the quasi-fixed factors, K_t and B_t, involve adjustment costs given as $c_k(I_t)$ and $c_b(N_t)$ where

$$I_t = (K_t - K_{t-1}), \qquad (14)$$

$$N_t = (B_t - B_{t-1}). \qquad (15)$$

Considine and Larson assume a Generalized Leontief function for the cost function G, and estimate G as a function of parameters (α), input prices (w), and output (Y), so $G = G(\alpha, w, Y)$. Taking first order conditions yields Euler equations for permit stocks and capital, and variable factor demand equations as functions of the same parameters (α), prices (w), and output (Y).

I then use their emissions per unit output demand equation, $\frac{x_{4t}}{Y_t}$, and the output cost function, G, to calculate the marginal abatement cost. Suppose that an economy-wide restriction on emissions were to drive up the price of emission permits (w_4). Then the marginal abatement cost is the change in the firm's total output cost ($\frac{\partial G}{\partial w_4}$) that is attributable to a change in their emissions ($\frac{\partial x_4}{\partial w_4}$). That is, the marginal abatement cost function, $c'(a)$, can be expressed as

$$c'(a) = -\frac{\frac{\partial G}{\partial w_4}}{\frac{\partial x_4}{\partial w_4}}. \tag{16}$$

As the price of emissions, w_4, changes, the firm's desired quantity of emissions varies according to the estimated parameters in the x_4 function. The change in output cost, G, associated with a change in w_4 is just the demand for emissions, x_4, so $\frac{\partial G}{\partial w_4} = x_4$ in the numerator of (16). The extra output cost associated with a small reduction in emissions is used here as the change in the cost of abatement. The total abatement cost is then the area under the curve of the marginal abatement cost function.

3.4 Solving the Model

I use the data tabulations given in Parry (2004) to calculate net burdens per quintile under grandfathered emissions permits. This data set consists of 2959 observations from the Consumer Expenditures Survey in 1997 and uses consumption as a proxy for annualized lifetime income. Electricity budget shares are calculated by aggregating spending on electricity across all members in a quintile and dividing by the value of total income of that quintile. Because it is difficult to obtain data on stock ownership in the electricity industry, the value of overall stock, bond, and other assets owned by a household are used instead. This is then aggregated over all households in a quintile and divided by total stockholdings to get the fraction of stocks owned by each quintile. Mean income levels per quintile, electricity budget shares, and fraction of stockholdings are reported in Table 3.1.

Table 3.1: Income and Budget Statistics

Income quintile	Income $	Elect. Budget Share	Fraction of stocks
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		

The mean level of household income across quintiles is $30,694. The poorest quintiles have greater budget shares for electricity, indicating that the policy is regressive at least on the uses of income side. Considering the raw data on fraction of stockholdings, it seems that the policy will also be regressive on the sources side, since the top quintile owns more than half of all stocks while the lowest quintile owns only 3.5%.

After deriving the marginal abatement cost function and then the total abatement cost function, the model can be easily solved. I use the estimated coefficients from Considine and Larson (2006) in order to solve for the abatement cost function. Considine and Larson (2006) estimate their model using a panel of 36 utility companies from 1995 to 1999. The range of companies in the sample include very large power systems as well as some much smaller utilities in the Midwest and Northeast. Summary statistics forselected variables are given in Table 3.2.

Table 3.2: Summary Statistics

	Mean	Std. Dev.	Minimum	Maximum
Output (million MwH)	22.38	24.97	2.23	123.47
Costs	Cents per KwH			
Low-sulfur fuel	0.33	0.45	0.01	2.51
High-sulfur fuel	1.17	0.43	0.05	2.12
Labor and maintenance	0.52	0.19	0.28	1.22
Emissions	0.07	0.06	0.01	0.39
Permit inventory costs	0.07	0.09	0	0.52
Capital Costs	1.08	0.39	0.34	2.47
Total Costs	3.23	0.68	2.1	6.12
Allowances	Thousand tons SO_2			
Stocks	79.1	168.8	0.4	1454.6
Allocations	167.3	218.2	9.4	1170.3
Net Purchases	-20.4	73.2	-343.1	163.4
Emissions	126.6	157.4	2.7	712

On average, each firm produced 22.38 million megawatt hours per year and had total costs of about 3.33 cents per kilowatt hour. Emissions costs are, on average, the smallest of the input costs at 0.07 cents per kilowatt hour. The mean level of permit stocks is equivalent to 79.1 thousand tons of SO_2, which is nearly half the average annual permit allocation from the EPA. On average, firms in the sample are net sellers of permits; this can be explained by environmental groups and speculators buying some of the permits.

After solving for $\frac{\partial G}{\partial w_4}$ and $\frac{\partial x_4}{\partial w_4}$, the marginal abatement cost function, *c′(a)*, given in (16) can be expressed as

$$\frac{x_4}{\frac{1}{2} w_4^{\frac{-3}{2}} Y(\alpha_{41} w_1^{\frac{1}{2}} + \alpha_{42} w_2^{\frac{1}{2}} + \alpha_{43} w_3^{\frac{1}{2}})} \tag{17}$$

where the *w*'s are the input prices, *Y* is total output, and the α's are the estimated parameters in the *G* cost function. The numerator is simply x_4, the factor demand of emissions, by definition.

Evaluating (17) at the sample means of w_1, w_2, w_3, w_4, and x_4 and the estimated parameters from Considine and Larson (2006) yields a value for the marginal abatement cost function of an average firm at mean post-regulation emissions levels. This value, calculated to be \$997/ton, represents the long-run marginal SO_2 abatement cost of the average firm.

The equilibrium permit price τ is set to \$997/ton. It should be noted that this value is much higher than the permit price used in Parry (2004), \$290/ton, which was taken from Carlson et. al.'s (2000) long-run marginal abatement cost estimate. Before

2003, observed permit prices were mostly in the \$100-200/ton range, but they began rising in 2003, peaking at almost \$1600/ton, before going back down in 2006.[4]

I assume that the marginal cost of abatement function is linear, as in Parry (2004), and set τ equal to the marginal abatement cost function specified in Parry (2004). Also from Parry (2004), pre-regulation emissions levels are 16 million tons, and Title IV of the 1990 Clean Air Act Amendments caps emissions levels at 9 million tons. The initial demand for electricity is taken from Parry (2004) and is found by aggregating electricity expenditure over all households and dividing by the 1997 retail price for electricity, \$68.50/Mwh. This yields an initial demand level of 3178 million Mwh. Using (5), γ can be solved from $\gamma(e_0 - e) = \tau$, where $e_0 - e$ is the rate of abatement undertaken by the average firm. This yields the following expressions for $c(a)$ and $c'(a)$:

$c(a) = 226{,}591a^2, \quad c'(a) = 453{,}182a.$

Then $c(a)$ is inserted into (9) to solve for p, using the average level of per unit abatement, the mean permit price for 1997, and the baseline retail price of electricity, p_0 = \$68.5/Mwh. Demand for the dirty good, given in (4), can now be evaluated with p and p_0. I use the values given in Parry (2004) for η and D_i^0. His η is taken to be -0.25 from the Haiku electricity sector model, and D_i^0 is computed as household i's budget share for electricity multiplied by income. Aggregate demand for the dirty good, given by (2), then follows, as well as E, aggregate emissions across the entire industry from (6).

[4] See www.epa.gov/airmarkets/progress for progress reports on the Acid Rain Program and permit prices data.

Government revenue, R, is calculated using E, τ, and λ, which then generates the two types of government transfers. As in Parry, I take λ to be 0.35, which approximates the overall effective tax rate due to corporate income taxes and dividend and capital gains taxes. Lastly, I compute the net burden for each quintile using the initial burden and the change in income. The change in income, ΔI_i, is the sum of the government transfer and profit income, calculated in Parry (2004) by aggregating the value of stocks, bonds, and other assets reported by each household.

3.5 Results

The net burdens for each quintile under both kinds of revenue recycling are reported in Table 3.3. The initial burdens increase with income, but the profit income and government transfers are high enough to offset this increase. The net burden for the distributionally neutral version of revenue recycling is greatest for the lowest-income quintile and smallest for the richest group. Thus the policy is very regressive; the top quintile is actually made better off as a result of the policy whereas the lowest-income group is made worse off than before. As a percent of income, the net burden in the proportional recycling case for the lowest-income group is nearly 5 times that for the top group in absolute terms.

Table 3.3: Burdens by income quintile under grandfathered permits

	Income Quintile				
	1	2	3	4	5
Using Considine and Larson estimates					
B_i	57.59	86.83	88.25	138.06	211.04
π_i	13.53	42.9	35.17	90.43	204.44
NB_i (Prop)	35.77	29.11	32.26	18.27	-43.69
% of income	0.347	0.158	0.123	0.05	-0.07
NB_i (LST)	14.4	14.3	23.42	17.97	-23.06
% of income	0.14	0.078	0.091	0.049	-0.037
Parry's results					
B_i	16	25	30	39	60
π_i	3	9	7	19	42
NB_i (Prop)	11	11	16	11	1
% of income	0.104	0.058	0.06	0.029	0.001
NB_i (LST)	5	7	14	12	9
% of income	0.048	0.039	0.055	0.033	0.015

Although the net burdens under the lump-sum transfers (G^{LST}) are smaller in comparison to the proportional recycling case, the lump-sum version of the policy is still highly regressive. The lowest-income group is made worse off by about \$14 while the top income group is better off by about \$23. However, the spread between the bottom and top income groups is smaller. The lowest income group has a net burden that is less than half of that under proportional recycling. Overall, the policy is very regressive regardless of how the permit rents are distributed, but, as expected, the lump-sump version creates a more equal spread of net burdens.

My results differ from Parry's in the degree of regressivity. Parry concludes that the SO_2 permit allowance policy is "intermediate regressive." That is, the net burden is positive for the highest-income group but smaller in absolute terms than the net burden of the lowest-income group. In the proportional version of the policy, the net burden is greatest in absolute terms for the middle quintile and smallest for the top quintile. In percentage terms, the lowest-income quintile bears the greatest burden, about 0.1% of their income, while the top group has the smallest, at 0.001% of their income. Similarly for the lump-sum revenue recycling case, the middle group bears the greatest net burden, but the lowest group now has the smallest. However, in percentage of income terms, the lowest and middle groups are fairly close while the top group has the lowest net burden as percent of income.

The use of empirical estimates in my analysis generated different results, but these results are not inconsistent with those in Parry (2004). Because Considine and Larson's estimates produced a price for emissions permits that is much higher than the one used by Parry, the cost of abatement in my analysis is higher, leading to a higher post-regulation electricity price as well much more tax revenue and thus greater (in absolute value) net burdens. In both my and Parry's analyses, the policy is found to be regressive; the difference in the results lies in the degree of regressivity.

Because grandfathered emissions permits increase the value of shareholdings in the regulated industry, wealthy households benefit more than they would under an emissions tax or auctioned permit system. In the model, an emissions tax and an auctioned permit system are equivalent policies; this is the case where $\lambda = 1$. In this instance, the government retains all of the scarcity rents, resulting in increased government transfers. Thus, it is expected that now the lower income groups will most likely be better off than under grandfathered permits because of increased transfers and the higher income groups may be worse off because of the lack of profit income. Net burdens per quintile under either an emissions tax or auctioned permit system ($\lambda = 1$) are reported below in Table 3.4.

Table 3.4: Net Burdens under an emissions tax or auctioned permits

	Income Quintile				
	1	2	3	4	5
Using Considine and Larson estimates					
NB_i (Prop)	33.9	44.5	28.76	54.16	67.36
% of income	0.329	0.242	0.111	0.149	0.108
NB_i (LST)	-27.15	2.09	3.51	53.32	126.32
% of income	-0.264	0.011	0.014	0.146	0.202

In the proportional transfer case, the lowest quintile is now slightly better off than under grandfathered permits (with grandfathered permits, $NB_1 = 35.77$). However, this version of the policy is still regressive in the sense that although the net burden of the top quintile is greater in absolute terms, it is still less as a percentage of income. In the lump sum transfer version of the policy, the lowest income group is made better off as a result of the policy, meaning that this policy is progressive. Unlike the grandfathered permit system, an emissions tax or auctioned permit system does not generate supernormal profits that accrue disproportionately to higher income groups. In a comparison of the results, it is clear that this wealth transfer to the richer quintiles makes a substantial difference in the incidence of the policy.

As was the case with grandfathered permits, the net burdens in my results are greater in absolute value than the net burdens calculated by Parry. He found that the lowest income group is $8 worse off with proportional recycling (compared to my almost $34) and $8 better off with lump-sum recycling (compared to my $27). The richest quintile in his analysis is $10 and $36 worse off with proportional and lump-sum recycling, respectively (compared to my $67 and $126). As before, the use of a much greater emissions permit price has exaggerated the net burdens in my results.

3.6 Monte Carlo Analysis

One major advantage of using econometric estimates in the abatement cost functions is that I can estimate the error bounds of the final results. Using Monte Carlo techniques and the estimated parameters from Considine and Larson (2006), I can calculate the 5th and 95th percentiles of the range of possible results. The Monte Carlo method entails taking a random draw from the joint distribution of parameters, evaluating the model, and then repeating the exercise 10,000 times in order to generate a distribution of results. I assume a multivariate normal distribution for the joint distribution of parameters, and calculate confidence intervals for the results in both the grandfathered permit policy and the emissions tax/auctioned permit system. The lower and upper bounds of the 90% confidence intervals for the distribution of results for the poorest and richest quintiles are reported in Table 3.5

Table 3.5: Upper and lower bounds on net burdens

	Quintile 1		Quintile 5	
	Proportional recycling	Lump-sum recycling	Proportional recycling	Lump-sum recycling
Grandfathered				
Upper Bound	56.08	22.66	-18.92	-9.92
Central Result	35.77	14.4	-43.69	-23.06
Lower Bound	15.33	6.01	-59.91	-27.65
Tax/Auctioned				
Upper Bound	52.47	-12.22	103.41	195.57
Central Result	33.9	-27.15	67.36	126.32
Lower Bound	14.42	-43	28.04	53.76

In the grandfathered permit system, the confidence interval for the net burden of the lowest quintile lies between about \$15 and \$56 in the proportional case and between about \$6 and \$22 in the lump sum case. For the top quintile these intervals are, respectively, between about -\$60 and -\$19 and between about -\$28 and -\$10. Thus, even the lower bounds on the intervals indicates a very regressive policy. The top income group is benefiting from the policy while the bottom group is made worse off.

For the emissions tax/auctioned permit system, with 90% confidence, the net burden for the bottom quintile is between \$14 and \$52 in the proportional transfer case and between about -\$43 and -\$12 in the lump sum case. In the lump sum version, these bounds indicate the progressive nature of these kinds of policies. While the poorest income group is made better off, the richest group is now worse off.

In his study, Parry (2004) is limited to performing sensitivity analysis where one key parameter is arbitrarily made larger or smaller. For example, he considers the effect of halving or doubling the slope parameter in his marginal abatement cost function. He does not report the results of this for SO_2 (he does so for carbon) but notes that changing this slope affects the price of electricity and thus, by an equal proportion, the net burden of all income groups. This kind of sensitivity analysis produces bounds on net burdens that may or may not be valid, depending on the likelihood that the parameter changes are in any way realistic. By using empirical estimates, the Monte Carlo method does, however, allow valid calculations of an upper and lower bound.

This Monte Carlo analysis yields a distribution of possible net burdens for each quintile. Evidence of regressivity for grandfathered permits is apparent from these ranges whereas an emissions tax/auctioned permit system can be progressive if the scarcity rents are distributed in lump sums.

3.7 Conclusion

Based upon these results, grandfathered emissions permits do have a disadvantage that auctioned permits or taxes do not. The combined effects of higher prices on polluting goods and increased stock values for wealthy shareholders create an unequal burden among households. In the case of the SO_2 emissions permit market, lowest-income groups are hurt the most as a result of the policy, while the highest-income group is actually benefiting. The way in which permit rents are recycled among households does affect the net burdens bore by different income groups, but even with lump-sum revenue transfers, the policy is still highly regressive. In light of these findings, the distributional effects of different pollution policies can be very different, and this fact may be worthwhile to consider in policy design.

Appendices

Appendix 1

Data on state environmental expenditures is available from the U.S. Census Bureau's *State Government Finances* reports. The environmental spending measure used in the analysis is the sum of expenditures in the following categories, where definitions and examples of each category are available in the *Government Finance and Classification Manual*:

Fish and Game: Conservation, improvement, development, and propagation of fish and game resources; and the regulation and enforcement of fish and game laws and rules.

Examples: Fish and game commissions; operation of fish hatcheries; stocking of lakes and streams; 'seeding' of waterways for propagation; regulation and enforcement of laws relating to commercial or sport fishing and wildlife, including inspection of processing facilities; fish and game wardens (including those with arrest powers); research studies and surveys to measure fish and wildlife populations; development and maintenance of wildlife management or hunting and fishing areas; management and protection of wildlife or fish species; and related public education programs.

Forestry: Conservation, development, management, and protection of forests and forest resources; regulation and inspection of forest products and industries; and provision of assistance to private or local government owners of woodlands.

Examples: Cooperative forest management; forest crop land administration; promotion of the use and marketing of forest products; forest fire prevention, control, and suppression; state forest land management; detection and control of insects and tree diseases; operation and support of tree seedling nurseries; regulation and inspection of timber producers, forest product industries, and other wood processors; acquisition, development, and management of state forests; reforestation activities; and urban and community forestry.

Other Natural Resources: Conservation, promotion, and development of natural resources (soil, water, energy, minerals, etc.) and the regulation of industries which develop, utilize, or affect natural resources. For Federal and state governments, covers activities not reported in other Natural Resources functions

Examples: Irrigation; drainage; flood control; soil conservation and reclamation including prevention of soil erosion; surveying, development, and regulation of water resources; regulation of mineral resources and related industries including land reclamation; wetlands and watershed management and protection; geological surveying and mapping; regulation of gas and oil drilling and production; dam and reservoir safety; public education programs related to the above; technical and fiscal assistance to private or other government efforts in these areas.

Parks and Recreation: Provision and support of recreational and cultural-scientific facilities maintained for the benefit of residents and visitors.

Examples: Golf courses, playgrounds, tennis courts, public beaches, swimming pools, play fields, parks, camping areas, recreational piers and marinas, etc.; galleries, museums, zoos, and botanical gardens; auditoriums, stadiums, recreational centers, convention centers, and exhibition halls; community music, drama, and celebrations including public support of cultural activities.

The following lists the types and classifications (with NTEE-CC codes) of environmental organizations that are matched to the four types of environmental spending for results shown in Table 1.3:

Fish and Game: Animal Protection and Welfare (D20), Wildlife Preservation and Protection (D30), Protection of Endangered Species (D31), Bird Sanctuaries (D32), Fisheries Resources (D33), Wildlife Sanctuaries (D34).

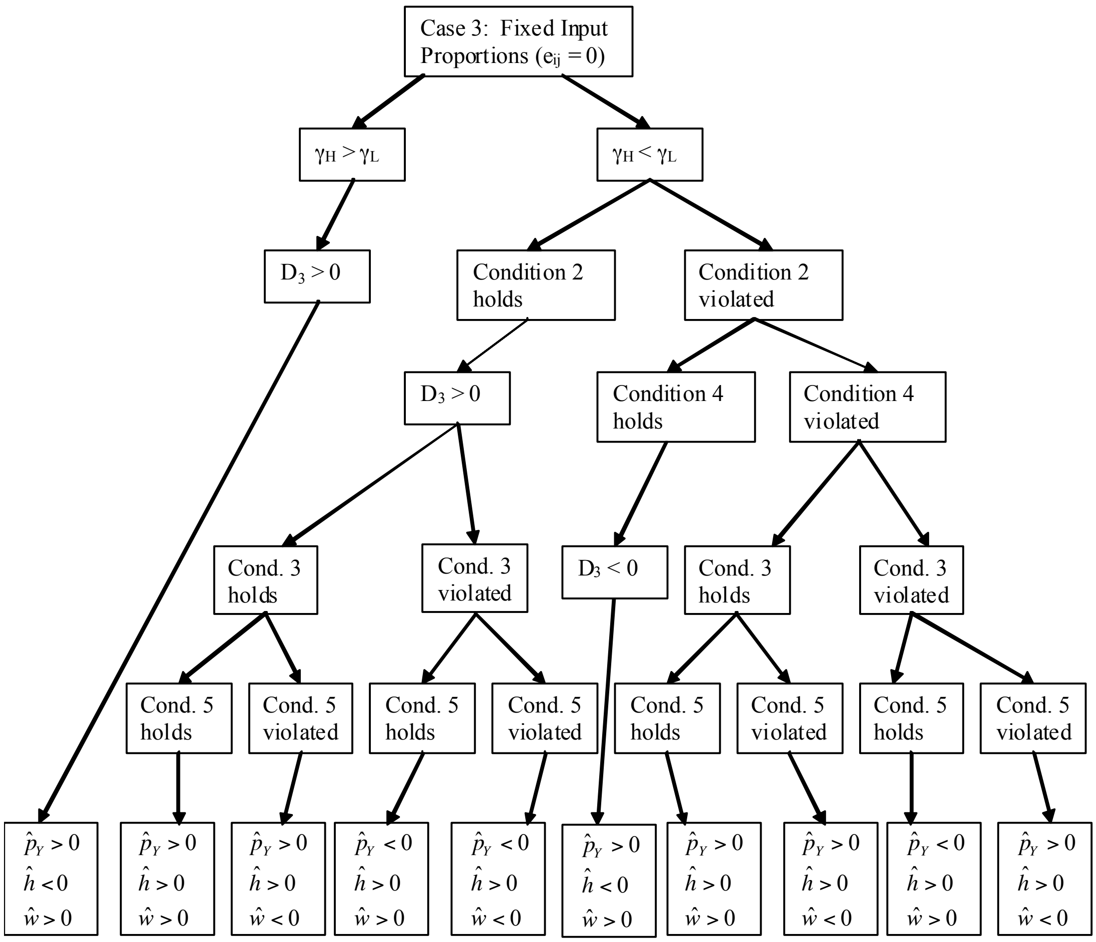
Forestry: Forest Conservation (C36).

Other Natural Resources: Natural Resources Conservation and Protection (C30), Water Resources, Wetlands Conservation and Management (C32), Land Resources Conservation (C34).

Parks and Recreation: Botanical Gardens and Arboreta (C41), Environmental Beautification (C50), Zoos and Aquariums (D50).

Appendix 2

Figure 2.1: Results for Case 3



Condition 2 (unskilled labor does not spend too disproportionately on Y):

$$(\sigma_U N + J)(\theta_{XH}\theta_{YL} - \theta_{XL}\theta_{YH}) + \frac{1}{C_H} h\overline{H}\left(\frac{Y_H}{Y_L} - \frac{X_H}{X_L}\right) > 0$$

Condition 3 (similar enough factor intensities): $\gamma_L - \gamma_H < \dfrac{C\sigma_X C_H}{h\overline{H}\left(\frac{X_H}{X_L} - \frac{Y_H}{Y_L}\right)}$

Condition 4 (different enough factor intensities):

$$\gamma_L - \gamma_H > \frac{-C\sigma_X}{(\sigma_U N + J)(\theta_{XH}\theta_{YL} - \theta_{XL}\theta_{YH}) + \frac{1}{C_H} h\overline{H}\left(\frac{Y_H}{Y_L} - \frac{X_H}{X_L}\right)}$$

Condition 5 (similar enough factor intensities): $\dfrac{\theta_{XH}\theta_{YZ}}{D_3}(\gamma_L - \gamma_H)(\sigma_U N + J)\hat{\tau}_Z < -\hat{\tau}_L$

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