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# Equity Effects in Energy Regulation

Carolyn Fischer\*  
William. A. Pizer<sup>§</sup>

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\* Resources for the Future

<sup>§</sup> Sanford School of Public Policy and Nicholas Institute for Environmental Policy Solutions, Duke University

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Carolyn Fischer and William A. Pizer\*

## Abstract

Some choices in energy regulation, particularly those that price emissions, raise household energy prices more than others. Those choices can lead to a large variation in burden both across and within income groups because of wide variation in household energy use. The within-income group variation in burden can be particularly hard to remedy. In this paper, we review alternative welfare perspectives that give rise to equity concerns within income groups (“horizontal equity”) and consider how they might influence the evaluation of environmental policies. In particular, we look for sufficient statistics that policymakers could use to make these evaluations. We use Consumer Expenditure Survey data to generate such statistics for a hypothetical carbon price versus a tradable carbon performance standard applied to the electric power sector. We show how horizontal equity concerns could overwhelm efficiency concerns in this context.

**Key Words:** equity, inequality, cap-and-trade, carbon price, performance standards

**JEL Classification Numbers:** D61, D63, Q48, Q52, Q58

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\* Carolyn Fischer is Senior Fellow at Resources for the Future (fischer@rff.org); Marks Visiting Professor at Gothenburg University; Visiting Senior Researcher at Fondazione Eni Enrico Mattei; and CESifo Research Network Fellow. William A. Pizer is Susan B. King Professor of Public Policy, Sanford School, and Faculty Fellow, Nicholas Institute for Environmental Policy Solutions, Duke University (william.pizer@duke.edu); University Fellow, Resources for the Future; Research Associate, National Bureau of Economic Research. Fischer is grateful for the support of the European Community’s Marie Skłodowska–Curie International Incoming Fellowship, “STRATECHPOL – Strategic Clean Technology Policies for Climate Change,” financed under the EC Grant Agreement PIIF-GA-2013-623783. This work was supported by the Alfred P. Sloan Foundation, Grant G-2016-20166028.

## Introduction

Economists often give primacy to the efficiency or cost-effectiveness of regulatory design, favoring Pigouvian pricing mechanisms for addressing environmental externalities. Equity or distributional effects are secondary, justified by the assumption that they can be dealt with by allocating the rents created by emissions pricing. Or, from a Kaldor-Hicks standpoint, it is sufficient to know that redistribution could hypothetically occur and make everyone better off when aggregate net benefits are maximized.

In this paper, we suggest that the primacy of efficiency or cost-effectiveness may be misplaced. When energy regulation raises energy prices, it is almost impossible to imagine making all consumers better off because of the wide variation in energy use across and within income groups. Pollution pricing gives rise to rents that can be used to address some distributional concerns. In particular, allocating rents based on income can achieve any desired level of progressivity. Such efforts still leave significant within-income-group variation. If our notion of equity is an equitable burden across households, where all households bear costs but wealthier households bear more, this variation is an unavoidable negative consideration. Society might prefer alternative regulatory policies that do not raise energy prices as much, minimizing these equity concerns, even if their aggregate cost is higher.

The acid rain trading program exemplifies the traditional perspective. An agreement was made to cap sulfur dioxide (SO<sub>2</sub>) emissions from coal-fired power plants at a specific level. With a general notion of how to allocate emissions rights, attention then shifted to horse-trading among the companies to address the exact distribution of burden (Cohen 1995). The perceived success of the acid rain trading program motivated significant attention to market-based policies

in the decades that followed, particularly surrounding carbon dioxide (CO<sub>2</sub>). This includes literally dozens of programs around the world (World Bank et al. 2016).

Perhaps the major difference between the acid rain trading program and CO<sub>2</sub> programs is the effect on electricity prices and the wider distribution of costs. In the acid rain program, the price of electricity was largely unaffected (Burtraw et al. 2005). Natural gas generators are often the marginal producers and do not emit SO<sub>2</sub>. Hence, power generation companies were the ones who felt the effects of the regulation and allocation choices. Market-based CO<sub>2</sub> programs, however, have the potential to raise electricity and other energy prices significantly. Millions of households, as well as businesses, will feel the direct effect of regulation as well as the choices about allowance or revenue allocations. The horse-trading is much more complex.

Under these circumstances, it seems hard to ignore equity and distributional concerns. In the acid rain program, it may have been sufficient to focus on efficiency because equity concerns were addressed directly by the affected parties—Coasean bargaining at its best. But when affected parties are numerous and diffuse, with elected or appointed representatives making these decisions, the fairness of the outcome is far from clear. Individual bargaining is replaced by generic rules, perhaps based on income or other observable demographics.

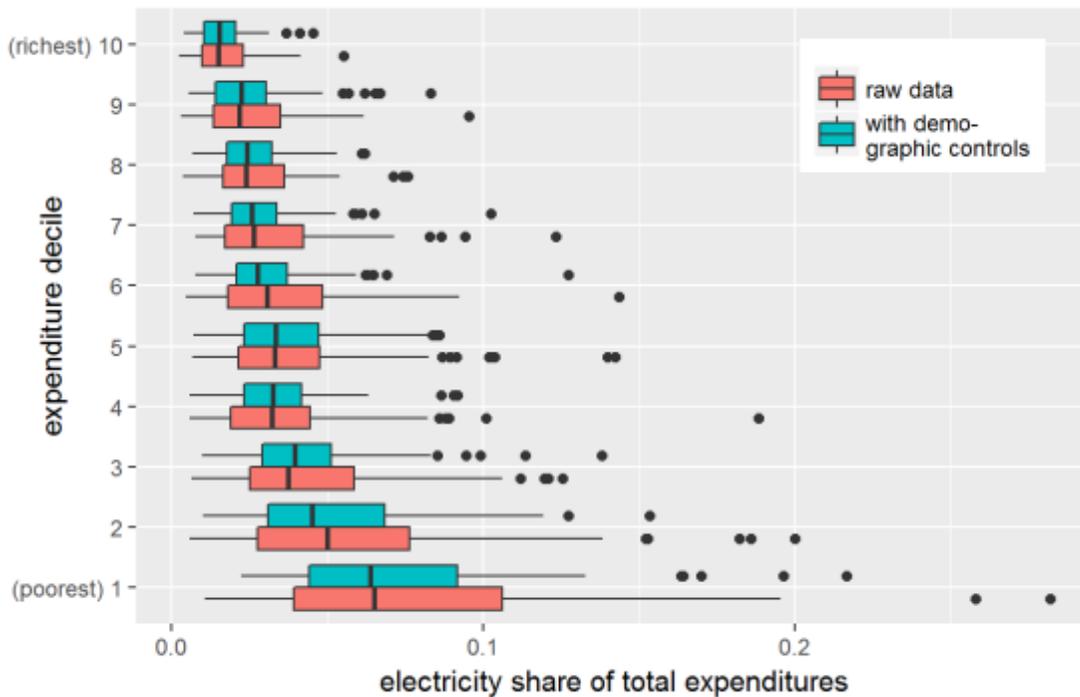
Part of our interest is the recognition that Pigouvian pricing policies can involve redistributions that are orders of magnitude larger than the net gain or loss to society. Burtraw and Palmer (2008) find that a pricing policy has net social costs of roughly \$0.5 billion annually, while consumers and producers lose more than \$21 billion in pollution payments. Depending on the allocation scheme, these payments may make their way back to those consumers and producers—or not. Among power generators, the aggregate loss is \$3 billion, but even this masks further redistribution. Nonpolluting generators gain \$6 billion while polluting generators

lose \$9 billion. Here, the redistribution arises from higher electricity prices, not just the pollution payments. The gain to nonpolluting generators (and corresponding loss elsewhere) cannot be eliminated by the government's allocation scheme. In contrast, performance standards involve much smaller redistributions but lead to higher social costs.

If there are unavoidable and unequal burdens, a big question is how to define the socially desirable distribution of costs to address environmental problems. This paper considers various definitions. We draw on the literature that discusses both the distribution of income, net of policy costs, and the distribution of the costs themselves. In particular, we focus on notions of *horizontal equity*. Most studies of the distributional effects of energy or CO<sub>2</sub> pricing have focused on the average or net effects by income group, or *vertical equity* (Mathur and Morris 2014; Dinan 2012; Metcalf 1999, 2008). Addressing vertical equity is generally the domain of income tax and transfer policies that target income.

The notion of horizontal equity emphasizes equal burden (in terms of policy cost and/or lost welfare) and prefers an outcome in which similarly situated households face similar burdens. This notion is generally associated with the idea that government policy should seek an equal burden across households and not a redistribution from rich to poor (Pigou 1928; Simons 1938). A preference for horizontal equity presents a particular challenge for climate and energy policy. Household energy use varies widely not only across income and demographics but also within any easily identifiable group. Much of this variation may be fixed and beyond the control of the households in the short term (e.g., because of local climate, housing stock, or power sector structure). Thus, climate and energy policy choices can have significant, unavoidable distributional effects that should be weighed alongside efficiency concerns.

To further motivate this idea, Figure 1 shows how household expenditures on electricity in the United States vary, based on the Consumer Expenditure Survey in 2015 (additional data and method details are discussed later). The red box plots show the distribution of electricity as a share of total expenditures by total expenditure decile, highlighting a strong relationship between expenditure share and income. Indeed, we find that 28 percent of the variation in electricity expenditure across all observations can be predicted by a simple regression on total expenditures. The blue box plots go a step further. They show how much we can reduce the variation within expenditure decile by using *all the available covariates in the data set*. That is, using a machine-learning algorithm, we search for combinations of variables in addition to income that predict electricity expenditure. We find 34 variables that do so, most of which are geographic or family composition indicators. We then subtract out the predicted component associated with those nonincome variables and produce box plots using the same decile groupings as before. In a regression context, the net result is to raise the fit to an adjusted R-squared of 56 percent with these other covariates. That is, all these variables together roughly double the predictive power of income alone, as measured by R-squared, *but nearly half the original, raw variation remains*. We can also see, visually, how much variation remains in the figure.



**Figure 1. Boxplots of electricity share by decile, highlighting the predictability of electricity expenditures using household income and other covariates (red is actual data; blue uses machine-learning algorithm to choose covariate controls)**

We find only a handful of academic studies that have focused on these questions. Poterba (1991) is perhaps the first example of an energy tax incidence analysis that tries to get at horizontal equity alongside vertical equity. Like the aforementioned studies that examine vertical equity and pollution or energy taxes, Poterba presents expenditure shares by decile without appealing to a welfare function or summary statistics. Without calling it horizontal equity, he is concerned about the heterogeneity of a gasoline tax within income groups, particularly the lowest. So, he adds to his table of expenditure shares by decile (his Table 2) another table highlighting “dispersion” that provides both the fraction of each decile above and below a particular expenditure share (in this case, zero and 0.3; see his Table 3). There, it is clear that the

average share of 0.039 for the lowest decile masks that 36 percent of this decile spend nothing on gasoline while 14 percent have an expenditure share exceeding 0.1.

Among practitioners, horizontal equity is a more regular concern. The typical approach has been to focus on the coefficient of variation within various income groups (Westort and Wagner 2002). Various approaches to computing the coefficient of variation have been discussed and are often presented for tax reform proposals.

Taking a more expansive approach, Rausch et al. (2011) use graphical figures to present the distributional effects of carbon pricing with various rebate approaches. They present box-and-whisker plots similar to ours and use them to highlight that even though some amount of progressivity and regressivity is certainly present, with the mean cost by decile ranging from 0 to 0.5 percent of income, a large number of households experience gains and losses of more than 1 percent.

Ultimately, welfare cost (like cost-benefit analysis itself) is not a singularly decisive metric for policymaking. Unless it is particularly intuitive, welfare measures may also obscure underlying information that would be relevant. For that reason, we subsequently ask what kind of information regarding horizontal equity might be presented to improve decisionmaking. That is, what are the inputs to measuring horizontal equity as opposed to the output of some welfare measure?

Our paper ultimately highlights two points. First, there is a range of ethical and theoretical notions of welfare and burden sharing for public policy. Some of these lead to welfare measures that depend on measures of variation within income groupings, not just across income. Second, different forms of energy regulation will have different effects on energy prices. Pricing pollution in the power sector, in particular, can have larger price effects than other forms of

regulation. These points together suggest a trade-off between efficiency and equity, particularly with pollution pricing. Without considering within-income-group distributional consequences, economic analyses of various policy alternatives risk excluding important consequences of interest to policymakers.

The remainder of the paper is organized as follows. The next section discusses various ethical and theoretical views about burden sharing. The range of views highlights (a) the importance of specifying what is meant by “equity,” and (b) that variation in costs—both between and within income groups—can lower welfare, depending on one’s perspective. We then consider two hypothetical policies, a carbon tax and a tradable performance standard applied to the electric power sector. We use household expenditure data to examine how these alternative policies might lead to different distributional and welfare consequences. We also discuss how well-targeted rebates of tax revenue might address distributional concerns. This analysis leads to our conclusion that there is a trade-off between efficiency and equity. Finally, we look at different ways to present distributional effects that are relevant for an emphasis on horizontal as well as vertical equity perspectives. We demonstrate that statistical and visual summaries can effectively capture and convey the necessary information.

## **Welfare theoretic motivations for a burden-sharing approach**

### ***Foundations of horizontal equity***

Equity and justice have long been principles in public economics (Elkins 2006). The principle of *equal sacrifice* dates at least to the 19th century. For John Stuart Mill (1871), “Equality of taxation ... means equality of sacrifice. It means apportioning the contribution of each person toward the expenses of government so that he shall feel neither more nor less

inconvenience from his share of the payment than every other person experiences from his.” This principle of equal sacrifice in paying for public goods could be interpreted as supporting progressive taxation, to ensure equal consequences in terms of utility (a version of vertical equity, though not as strong as redistribution) and to ensure that equally situated persons are treated equally (horizontal equity). The 19th-century utilitarian philosopher and economist Henry Sidgwick considered equal sacrifice the “obviously equitable principle—assuming that the existing distribution of wealth is accepted as just or not unjust” (Weinzierl 2012). In other words, assuming society does not want to engage in additional income redistribution, the burdens of financing government should be shared equally.

The distinction between vertical and horizontal equity formally came to prominence in the early and mid-20th century, as documented by Elkins (2006, 43):

The idea that the tax structure should impose similar burdens on equally well-off individuals was apparently first mentioned by Henry C. Simons and A.C. Pigou in the first half of the twentieth century. See HENRY C. SIMONS, *PERSONAL INCOME TAXATION* 30 (1938) (“[W]e may say that tax burdens should bear similarly upon persons whom we regard as in substantially similar circumstances ...”); *id.* at 106 (“[T]axes should bear similarly upon persons similarly situated.”). Pigou explicitly differentiated between those principles of equality applicable to equally well-off individuals and those relevant to unequally well-off individuals—i.e., between horizontal equity and vertical equity: “[E]qual sacrifice among similar and similarly situated persons is an entirely different thing from equal sacrifice among all persons.” A.C. PIGOU, *A STUDY IN PUBLIC FINANCE* 44 (3d rev. ed. 1949).

The term “horizontal equity,” as referring to equal treatment of equally well-off taxpayers, came into common usage during the 1960s and 1970s, having been coined in R.A. MUSGRAVE, *THE THEORY OF PUBLIC FINANCE* 160 (1959). Adoption of the term “horizontal equity” nevertheless took several years. For instance, in 1965, when writing of the principles of tax theory, Joseph T. Sneed referred to equity and to mitigating economic inequality as two of those principles. When discussing mitigating social inequality, he used the term “vertical equity.” However, the principle that similarly situated individuals should pay the same tax was referred to merely as “equity.” Joseph T. Sneed, *The Criteria of Federal Income Tax Policy*, 17 *STAN. L. REV.* 567 (1965).

Although horizontal equity has been generally accepted as a principle of tax policy, operationalizing it into a social welfare function with solid economic foundations has proved somewhat elusive. Kaplow (1989) is particularly critical of the application of horizontal equity to analyses of comprehensive tax reform, where it is unclear why the status quo is particularly relevant. However, unlike broad-based tax reform, environmental policy is an indirect tool for addressing vertical inequality. If one believes that the overall tax system has evolved to address social inequality to the extent that the existing distribution is “just,” then a reasonable equity principle for allocating the burden of environmental policy is to avoid distortions to that distribution. That is, sacrifices relative to the status quo should be equal.

Elkins (2006, p. 73) emphasizes the role of the morality of the preexisting market distribution:

Horizontal equity requires that those who had equal shares in the pre-tax distribution receive equal shares in the post-tax distribution. Thus, horizontal equity can be seen as an application of Aristotelian justice in which “merit” is defined as well-being in the pre-tax, or market, distribution. Those whose shares in the market distribution were equal are entitled to equal shares in the post-tax distribution. As the moral basis of any conception of Aristotelian justice depends upon the fairness or morality of its definition of merit, the moral basis of horizontal equity depends upon the moral standing of the market distribution.

A related concept involves the extent of redistribution that can occur. The *Pigou-Dalton axiom* holds that a social welfare function should prefer allocations that are more equitable, as long as redistribution does not change the ranking of individuals. Adler (2013, p. 1) defends this “prioritarian” view, adjusting the measure of well-being according to responsibility: “if one person is at a higher level of well-being than a second, and the worse-off one is not responsible for being worse off, then distributive justice recommends a non-leaky, non-rank-switching transfer of well-being from the first to the second, if no one else’s well-being changes.” This

responsibility adjustment may have interesting implications in our context, taking into account the ability to invest in energy efficiency and alter energy consumption habits.

The importance of the status quo (or other reference point) and ranking is highlighted in behavioral and “happiness” economics. Duesenberry (1949) first proposed the *relative income hypothesis*, stating that individual utility depends on both own income and income relative to others, to explain why savings behavior seemed independent of absolute income. With happiness economics, self-reported measures of well-being came to be accepted as reasonable measures for individual utility (e.g., Clark and Oswald 1994). Empirical analysis of the relative income hypothesis reveals a lack of agreement about the direction of the effect, however, with estimates being highly sensitive to both the definition of the reference group and the estimation strategy employed (Brown et al. 2015).

Boyce et al. (2010) argue instead for *rank-income hypothesis*, finding that the ranked position of an individual’s income within a comparison group predicts general life satisfaction, whereas absolute income and relative income compared with a social reference-group norm have no effect. They also find that individuals weight upward comparisons more heavily than downward comparisons: “According to the rank hypothesis, income and utility are not directly linked: Increasing an individual’s income will increase his or her utility only if ranked position also increases and will necessarily reduce the utility of others who will lose rank” (Boyce et al. 2010, p. 471). Thus, a policy measure that does not disturb the net income distribution should have minimal effects on utility.

Theoretical foundations for reference-based utility were offered by psychologists Kahneman and Tversky (1979), who propose *prospect theory* as a way to incorporate observed behavioral biases in decisionmaking. Central concepts are that people evaluate outcomes relative

to a reference point, and gains are evaluated differently from losses, expressed by “loss aversion.” Kahneman and Tversky were not explicit about the origin of the reference point, but proposed candidates have been the expected outcome (Kőszegi and Rabin 2006, 2007, 2009), the status quo (the “endowment effect” in Thaler 1980), or the average outcome of others. Although prospect theory was postulated for decisionmaking under uncertainty (and also includes concepts related to biases in evaluating high-risk, low-probability events), Michaelson (2015, p. 202) argues that the same biases also hold for resource distribution problems in the aggregate; his findings “suggest that neither utilitarian nor Rawlsian objectives will properly describe what most people believe is fair.” Thus, reference-point biases offer additional support for considering aspects of horizontal equity in policymaking.

### ***Auerbach and Hassett***

The long history of welfare economics has tended to emphasize a conceptual framework for defining how individual outcomes, and preferences over those outcomes, are mapped into social preferences.<sup>1</sup> A fairly typical approach would be to define a mapping from individual utility  $u_i$  to social welfare =  $W(u_1, u_2, \dots, u_N)$  where the  $u_i$  are cardinal and interpersonally comparable utility measures. Social welfare theory has then gone on to consider various forms of the function  $W(\cdot)$ .

As noted by Kaplow (1989) and others, operationalizing horizontal equity into a welfare function with desirable properties is not easy. Desirable properties include not only a preference for horizontal equity but also a preference for vertical equity and sensible magnitudes such that insignificant changes to income that affect rank do not have aggregate welfare effects

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<sup>1</sup> See Chapter 23 of Mueller (2003) for a discussion of traditional social welfare theory.

disproportionate to large changes that preserve order. Inevitably, some compromise is necessary, as cautioned by Arrow's *impossibility theorem*: agents' ordinal preferences cannot be aggregated into a social preference ranking while still meeting a full set of reasonable criteria for fairness and consistent consumer preferences.<sup>2</sup>

One approach, taken by Auerbach and Hassett (AH, 2002), is to modify a "traditional" welfare function, expressed in terms of income, to account for horizontal inequality. If individuals are grouped into  $I$  bins with  $N_i$  individuals, where each has an identical income,  $y_i^0$ , in a reference case, AH propose a welfare function for any policy case given by<sup>3</sup>

$$W_{AH} = \left[ \sum_i N_i \left( \frac{1}{N_i} \sum_j (y_{ij} + \Delta y_{ij})^{1-h} \right)^{\frac{1-v}{1-h}} \right]^{\frac{1}{1-v}} \quad (1)$$

We can rewrite their welfare measure as a function of average income within each reference group, multiplied by an adjustment factor ( $H_i$ ) that depends on a weighted average of the horizontal equity measures:

$$W_{AH}' = \left[ \sum_i N_i (\bar{y}_i H_i)^{1-v} \right]^{\frac{1}{1-v}}, \text{ where } H_i = \left( \frac{1}{N_i} \sum_j \left( \frac{y_{ij} + \Delta y_{ij}}{\bar{y}_i} \right)^{1-h} \right)^{\frac{1}{1-h}}.$$

This framework blends the issue of horizontal equity (valued by the parameter  $h$ ) with that of vertical equity (valued by the parameter  $v$ ). With  $h \geq 0$  and  $v \geq 0$ , welfare is increasing and concave in individual income. Note that the inside term is the adjusted income for group  $i$ , multiplied by a horizontal equity measure reflecting "local" inequity around  $i$ . In the reference

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<sup>2</sup> These criteria are completeness, transitivity, Pareto optimality, nondictatorial, and pairwise independence.

<sup>3</sup> Again, we adjust some variable names to avoid confusion with others already designated.

case,  $y_{ij}^0 = \bar{y}_i^0$  and everyone in the group has the same income. In the policy case, there is some average change in income,  $\bar{y}_i - \bar{y}_i^0$ . But welfare in the new state is adversely affected by the dispersion of the  $y_{ij}$  based on the curvature of the function given by  $h$ .

One implication of this model is what an “equitable” distribution of costs looks like. It clearly lowers welfare to introduce any variation within those groups. Thus, it penalizes “horizontal inequity” within groups. Across income groups, the welfare-maximizing distribution of costs would (a) put all the burden on the wealthiest group, and moreover (b) encourage transfers from rich to poor as much as possible. In this way it maintains a traditional view of equity across groups, emphasizing redistribution where moving income from rich to poor groups will raise welfare unless  $\nu = 0$ . When  $\nu = 0$ , there is still no value placed on *sharing* a burden across income groups; the welfare function is simply indifferent to which group pays as well as any redistribution between groups—so long as each member of the income group faces the same consequence. One appealing feature of AH is that there is a smooth transition to the standard welfare model. As  $h \rightarrow \nu$ , the AH function becomes a standard utilitarian welfare function.

A less desirable feature is the difficulty of interpreting the magnitude of horizontal equity effects. Since changes in energy costs are small relative to income,  $(y_{ij} + \Delta y_{ij}) / \bar{y}_i$  will be close to 1. Indeed, even for the examples in AH that focused on income taxes, all of their estimates of  $H_i$  are above 99 percent. Although that may be sufficient differentiation for comparing horizontal inequality across income percentiles or over time or with major tax reforms, it is less clear how one would use this measure for judging the equitable allocation of the costs of environmental regulation.

A more practical issue is that every household has a different income, so this approach cannot be implemented without modification. AH propose instead to consider a window around each observation and see how much inequality has increased is in that window relative to the reference case. The authors themselves acknowledge limitations to using their measure of inequality for welfare judgments: “there is also little guidance as to the appropriate relative weighting, or how to determine individual reference groups. The exploration of the consequences of different attitudes toward horizontal and vertical inequality is an important subject of future inquiry.”

Our own issue with AH is that, with this modification, it is very difficult to describe the welfare-maximizing distribution of burden for a given policy. Like traditional welfare functions, there is a preference for transfers from rich to poor. But there is an additional preference for more local transfers from rich to poor. For this reason, we look for a welfare framework that operationalizes the previously discussed notion of equal sacrifice without rewarding redistribution per se.

### ***Negishi***

Negishi (1960) formalized an insight for evaluating policies that do not have a primary goal of manipulating the distribution of income. By weighting individual utilities by the inverse of the marginal utility of income, the aggregated social welfare function replicates the market distribution, given initial endowments, and is consistent with Pareto optimality. Negishi weights have been used extensively in numerical models for evaluating the benefits of climate policy in an international context, where per capita incomes vary widely, and also for intergenerational effects (Abbott and Fenichel 2014).

Negishi weighting essentially removes the notion of vertical equity from the social welfare function. The result is then to focus on the aggregate effects; however, it can also be useful in notions of horizontal equity, when combined with other frameworks.

### **Slesnick**

Slesnick (1989) uses a welfare function based on deviations in household utility  $\Delta u_i$  from an initial reference point  $u_i(y_i^0)$ . Here, we have simplified his model to a case where utility is solely a function of a single good,  $y$ , that we can view as income. The welfare function begins with a weighted average of utility changes across households, from which is subtracted a measure of deviations from this average. In this way, variation across households in their utility change is costly in terms of welfare, and the welfare-maximizing policy would generally involve an equal utility change across all households. This is the equal sacrifice notion. Slesnick's welfare function can be written as

$$W_s = \overline{\Delta u}(y_i) - \gamma \left( \sum a_i |u_i(y_i) - \overline{\Delta u}|^{1+\rho} \right)^{\frac{1}{1+\rho}} \quad (2)$$

where

$$\overline{\Delta u} = \sum a_i \Delta u_i$$

And  $a_i$  represents normalized Negishi weights:

$$a_i = \frac{u'(y_i^0)^{-1}}{\sum_j u'(y_j^0)^{-1}}$$

Note that the welfare function is increasing in the average utility change but decreasing in a measure of deviations of changes in individual utility from the average—i.e., horizontal inequity. By weighting the individual deviations by the inverse of marginal utility, we

completely disentangle total costs and burden sharing. That is, without defining the weights in (2), rearranging costs to minimize deviations in utility changes may affect average utility. When these weights are used, however, the average utility change reduces to a rescaled average income change:

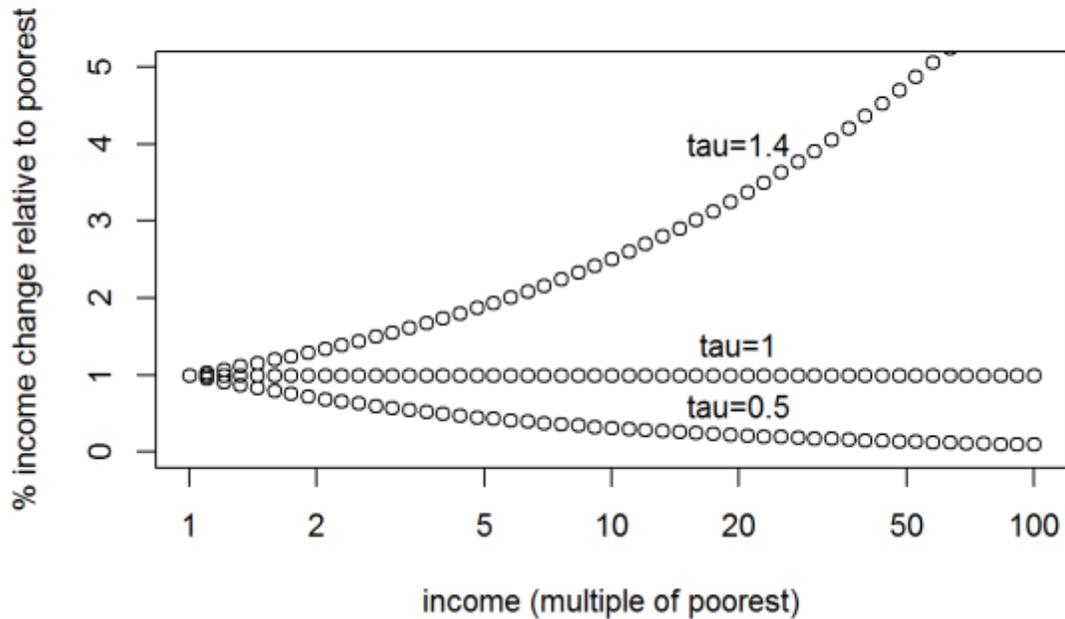
$$\overline{\Delta u} = \sum a_i \Delta u_i = \frac{\sum_i u'(y_i^0)^{-1} \Delta u_i}{\sum_i u'(y_i^0)^{-1}} = \frac{\sum_i u'(y_i^0)^{-1} u'(y_i^0) \Delta y_i}{\sum_i u'(y_i^0)^{-1}} = \bar{u}' * \overline{\Delta y}$$

where  $\overline{\Delta y} = N^{-1} \sum \Delta y_i$  is the simple average change in income and  $\bar{u}' = (N^{-1} \sum_i u'(y_i^0)^{-1})^{-1}$  is the harmonic average marginal utility. Here, we have assumed  $\Delta u_i = u'(y_i^0) \Delta y_i$ , which makes sense for relatively small policy changes. In this way, we can reallocate dollar costs across households without affecting the first term. The second term is then minimized, and welfare maximized, with  $\Delta u_i(y_i) = \overline{\Delta u}$  for all households.

What does a constant change in utility look like across households with different income levels? That obviously depends on the shape of the utility function. Suppose we assume iso-elastic utility, where

$$u_i(y_i) = u(y_i) = (1 - \tau)^{-1} y_i^{1-\tau}. \quad (3)$$

For different values of  $\tau$ , we can derive the welfare-maximizing, constant-change-in-utility cost allocations, as shown in Figure 2. When  $\tau = 1$  (i.e., log utility), the welfare-maximizing cost allocation is an equal percentage of income for all households. When  $\tau = 1.4$ , a household with 50 times the income of the poorest household should spend 5 times the share of income as the poorest, etc.



**Figure 2. Welfare-maximizing cost allocation under Slesnick welfare function and different assumptions about elasticity of marginal utility with respect to consumption**

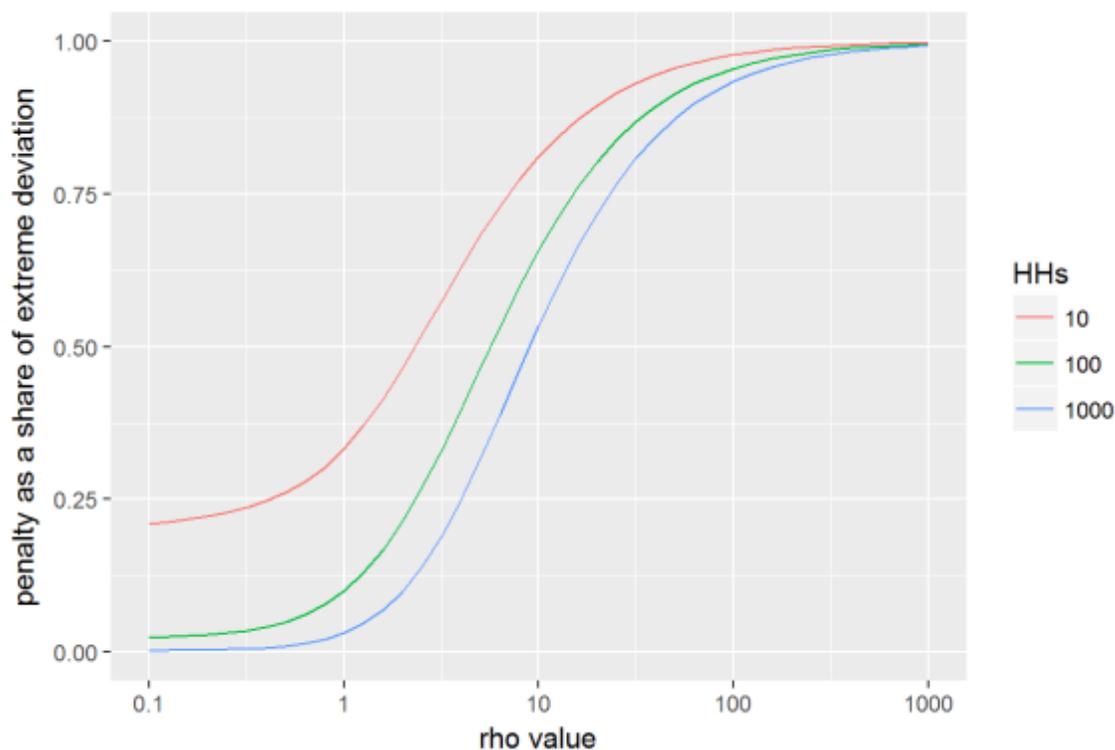
The Negishi weights have another important and related consequence for the Slesnick welfare function. Imagine we are examining an outcome where  $0 > \Delta u_i(y_i) - \bar{\Delta u} > \Delta u_j(y_j) - \bar{\Delta u}$ . Both households are bearing more than the average burden,  $\bar{\Delta u}$  (a negative value). But household  $j$  is bearing a more extreme adverse burden. Consider a small transfer of cost from household  $i$  to  $j$ . Along the lines of the Pigou-Dalton principle, we would want this transfer to improve welfare, since it would reduce the more extreme deviation from the average utility change without affecting individuals other than  $i$  and  $j$ . Based on the Negishi weights, this will be

true so long as  $\rho > 0$ . That is, the derivative of the second term in (2) for a reallocation  $dy$  from  $i$  to  $j$  would be

$$\begin{aligned} & (1 + \rho) \left( a_j |\Delta u_j - \bar{\Delta u}|^\rho u'(y_j^0) - a_i |\Delta u_i - \bar{\Delta u}|^\rho u'(y_i^0) \right) dy \\ &= \frac{(1 + \rho)}{\sum_i u'(y_i^0)^{-1}} (|\Delta u_j - \bar{\Delta u}|^\rho - |\Delta u_i - \bar{\Delta u}|^\rho) dy, \end{aligned}$$

which is positive so long as  $\rho > 0$ , given the larger deviation in for household  $j$ . If  $\rho = 0$ , Pigou-Dalton holds only weakly. Welfare is not improved by such transfers, but neither is it reduced. In that case, we do not care about more extreme burdens.

This point highlights the importance of  $\rho$  in the Slesnick function. One way to think about this is to imagine moving off the welfare-maximizing cost burden by adding to the cost burden of one household by reducing it for everyone else. Assume the households all have the same initial income. How much does the second term depend on the deviation of that one, worse-off household versus everyone else? Figure 3 shows how the second term in (2), ignoring the weight  $\gamma$ , varies with  $\rho$ . The vertical axis shows the value of this penalty term as a share of the deviation of that one, worse-off household. That is, if one individual bears a cost \$1 higher than the mean, and the vertical axis reads 0.25, the penalty is \$0.25 (scaled by marginal utility). Different colors indicate different total numbers of households  $N$ . For a small value of  $\rho$  on the order of 1, the penalty is an average of the deviation of that one, worse-off individual and the much smaller deviations of the other  $N - 1$  households. For larger populations of households (HHs), the penalty falls toward zero. Note that the penalty does not depend on whether the idiosyncratic household is made worse or better off; all that matters is that one household has a deviation from the others (and all then have a deviation from the mean utility burden). For larger values of  $\rho$ , the



**Figure 3. Inequality penalty as share of utility deviation for most extreme deviation, for different values of parameter  $\rho$  and different numbers of households  $N$**

penalty tends toward the value of the extreme deviation. Here, the penalty for unequal burdens depends entirely on the most unequally burdened (whether good or bad).

The only remaining parameter is  $\gamma$ . This simply reflects the relative importance of equity, measured by the second term, and overall cost, measured by the first. If  $\gamma$  is zero, there is no concern for the distribution of costs. For large values of  $\gamma$ , we are increasingly willing to accept a higher overall cost to society in order to achieve a more equitable burden. Slesnick picks  $\gamma$  to be as large as possible while still satisfying the constraint that increasing any  $y_i$  from the initial  $y_i^0$  should increase welfare.

## **Prospect theory**

A similar representation can be derived from prospect theory. Kahneman and Tversky (1979) argue that gains or losses are evaluated relative to a reference point and welfare exhibits loss aversion and diminishing sensitivity. Consistent with prospect theory, Tversky and Kahneman (1992) offer a value function for a gain or loss  $x$  with the power function form  $v(x) = x^\alpha$  for  $x \geq 0$ , and  $v(x) = -(1 + \lambda)(-x)^\beta$  for  $x < 0$ , where  $\alpha > 0$ ,  $\beta > 0$ , and  $\lambda > 0$  implies loss aversion.<sup>4</sup> Tversky and Kahneman also add probability weightings that overweight extreme (low-probability) outcomes, using a cumulative probability distribution function.<sup>5</sup> When all outcomes are losses, the cumulative prospect preference function is identical to a rank-dependent expected utility preference function (Quiggin 1993; Neilson and Stowe 2002).

Let us create an aggregate welfare function  $W_{PT}$  reflecting the principles of prospect theory, with underlying assumptions analogous to those in  $W_S$ . Assume that  $\alpha \approx \beta \approx 1$ .<sup>6</sup> Furthermore, the gain or loss is assessed relative to an individual reference point,  $r_i$ , so  $x = \Delta y_i - r_i$  where  $\Delta y_i$  is the income change for household  $i$ . We write an aggregate welfare function, including individual reference points and loss aversion:

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<sup>4</sup> al-Nowaihi et al (2008) show that preference homogeneity in the presence of loss aversion then requires  $\alpha = \beta$ . Diminishing sensitivity would require  $\alpha \in (0,1)$ , implying risk aversion over gains and risk seeking over losses.

<sup>5</sup> Tversky and Kahneman (1992) use the weight  $w(\pi) = \pi^\eta / (\pi^\eta + (1 - \pi)^\eta)^{1/\eta}$ , while Prelec (1998) proposes  $w(\pi) = e^{-(\ln \pi)^\eta}$ , where  $\pi$  is the probability.

<sup>6</sup> This assumption implies that marginal utility is locally flat, allowing for straightforward aggregation.

$$\begin{aligned}
W_{PT} &= N^{-1} \sum_{i=1}^N r_i - (1 + \lambda) \underbrace{\left( N^{-1} \sum_{i=1}^{i^*} |\Delta y_i - r_i| \right)}_{\text{aggregate losses}} + \underbrace{\left( N^{-1} \sum_{i=i^*+1}^N |\Delta y_i - r_i| \right)}_{\text{aggregate gains}} \\
&\quad \text{reference points} \\
&\equiv \bar{\Delta y} - \lambda \left( N^{-1} \sum_{i=1}^{i^*} |r_i - \Delta y_i| \right)
\end{aligned} \tag{4}$$

where we have ordered individuals from greatest loss to greatest gain,  $i^*$  is the last individual suffering a loss, and  $\lambda > 0$  for loss aversion. Suppose the reference point is some notion of a fair cost burden of a particular aggregate cost,  $\sum \Delta y_i$ , so  $\sum r_i = \sum \Delta y_i$ . We can rewrite expression (4) to show that a mean-preserving increase in the absolute deviations of outcomes reduces welfare:

$$\begin{aligned}
W_{PT} &= \bar{\Delta y} - \lambda \left( N^{-1} \sum_{i=1}^{i^*} |r_i - \Delta y_i| \right) + \frac{\lambda}{2} \left( N^{-1} \sum_{i=1}^{i^*} |r_i - \Delta y_i| - N^{-1} \sum_{i=i^*+1}^N |\Delta y_i - r_i| \right) \\
&= \bar{\Delta y} - \frac{\lambda}{2} \left( N^{-1} \sum_{i=1}^N |r_i - \Delta y_i| \right)
\end{aligned}$$

This works out to be the same expression as the Slesnick welfare function when its curvature is also assumed away ( $1 + \rho = \alpha = \beta = 1$ ):

$$\begin{aligned}
W_S' &= \left( N^{-1} \sum_{i=1}^N u'(y_i^0)^{-1} \right) W_S \\
&= \bar{\Delta y} - \gamma \left( N^{-1} \sum_{i=1}^N \left| \Delta y_i - \frac{\bar{\Delta u}}{u'(y_i^0)} \right| \right) \\
&= \bar{\Delta y} - \gamma \left( N^{-1} \sum_{i=1}^N \left| \Delta y_i - \frac{a_i}{N^{-1}} \bar{\Delta y} \right| \right)
\end{aligned}$$

Here, Slesnick's  $\gamma$  is the prospect theory's  $\lambda / 2$ . And prospect theory's reference point  $r_i$  is set to  $(a_i / N^{-1}) \bar{\Delta y}$  in Slesnick's formulation. Prospect theory leads to a more generic notion of welfare-maximizing burden, which is otherwise determined by equal utility change in the Slesnick formulation. The Slesnick framework allows more easily the incorporation of a more

general notion of inequality aversion that can be sensitive to more extreme deviations from the welfare-maximizing burden.

Ultimately, using any of these functional forms requires assigning values to what are at best subjective parameters of the social welfare function—for example, the degree of inequality or loss aversion and the notion of fair burden. However, using data, we can calculate various statistics related to the distribution of effects associated with different policy options that could subsequently be used to inform chosen welfare functions. These include the average effects on households by income group and the standard deviation or average absolute deviation of effects by income group, among others.

### **Distributional effects of cap-and-trade versus tradable performance standards in the electricity sector**

To make our concerns about an equity-efficiency trade-off concrete, we consider a stylized example of alternative policies in the electric power sector. We use this to show that although there may be overall cost savings to society from a Pigouvian pricing scheme versus non-Pigouvian regulation, such pricing comes with almost unavoidably higher equity costs—depending on our welfare framework. More precisely, Pigouvian pricing schemes impose a higher direct burden on households. This burden is related to the price paid for the allowed pollution (or other externality). This payment amounts to either tax revenues or allowance allocation that can, in turn, be distributed in ways that address equity concerns. However, when (a) effects across households vary in significant ways that cannot be targeted by practical, rules-based distribution, and (b) we adopt a welfare function that emphasizes a shared burden of policy cost, then we find this unavoidably higher equity cost. As suggested by Figure 1 in the

Introduction, we believe condition (a) is indeed the case. Condition (b) remains an ethical or political question.

This particular choice of policies is a relevant consideration for energy and environmental policies. Both cap-and-trade and tradable performance standards have been proposed for the electric power sector over the past decade (Waxman 2009; Bingaman 2012). The Clean Power Plan provided states with options for both rate-based and mass-based trading—in other words, tradable performance standards or cap-and-trade. Many other regulations are implemented as tradable performance standards, including fuel economy standards for light-duty vehicles, the 1980s lead phasedown in gasoline, and California’s low-carbon fuel standard. Perhaps there are better arguments for such policies than economists have previously recognized.

To make concepts clear, we first present a simple analytic model to explain major differences between the two policies. We then use data from the Consumer Expenditure Survey, shown earlier in Figure 1, to put numbers on the household effects of the stylized policies. Finally, we show how these effects look when viewed through the lens of welfare functions from the previous section. We emphasize the potential for visual information and/or summary statistics to convey the underlying information necessary to evaluate welfare. This presentation method avoids the black-box nature of a welfare calculation and also avoids having to specify welfare parameters in advance.

### ***A simple economic model for comparing policies***

We simplify our welfare analysis by focusing on the case of perfectly inelastic electricity demand. As discussed in the Appendix, this assumption implies that both tradable performance standards (TPS) and cap-and-trade (CAT) policies will result in identical combinations of

emissions level and emissions credit price (and, of course, electricity consumption). When we compare policies that target the same emissions level, two differences emerge: electricity prices and the disposition of emission rents. Under TPS, the emissions allowance value is rebated as a subsidy to electricity production, based on the performance rate  $R$ :

$$p_z^R = C(p_m) - p_m R$$

Here,  $C(p_m)$  is the unit production cost of electricity,  $p_m$  is the allowance price, and  $p_z$  is the electricity price. The superscript  $R$  reflects the outcome under the rate-based TPS. Under CAT, electricity price equals unit cost,

$$p_z^C = C(p_m)$$

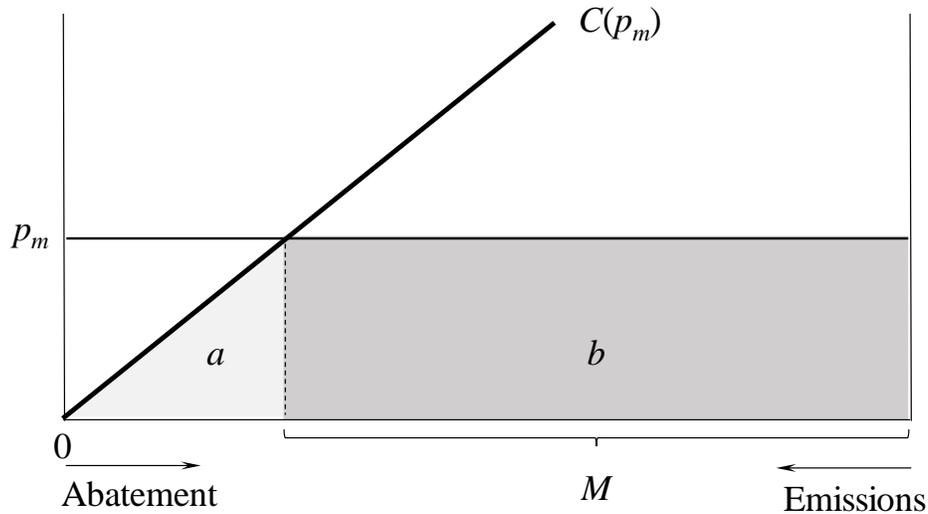
where the superscript  $C$  reflects the outcome under the CAT. The allowance value is instead rebated to each household  $i$  based on its assigned share  $s_i$ . That is, each household receives  $s_i p_m M$ , where  $M$  is the aggregate emissions level. As the emissions level (and emissions rate) is the same under both policies, we have  $M = R \times Z$ , where  $Z$  is aggregate electricity consumption.

This approach has two advantages. One is that household utility can be represented as an aggregate of nonelectricity consumption. Because household electricity is assumed fixed, we can abstract from its role in the utility function. We can approximate each household's change in utility as its increased electricity costs subtracted from its share of any allowance value. With a single nonelectricity good, this approximation would be exact (as we show in the Appendix). More generally, we would need an appropriate aggregate consumption good and production model that also considered the effect of electricity prices on other goods as well as source-side effects.

The other advantage is that we avoid having to specify more detail about electricity demand and supply. All that matters for the policy comparison is a notion of (a) an increase in the unit cost of electricity associated with an emission target, and (b) the associated allowance value that is either rebated in the electricity price under TPS or assigned to households under CAT.

At first blush, this approach may seem counterproductive. The underlying point of the paper is that there is an equity-efficiency trade-off. By assuming perfectly inelastic energy demand, we are abstracting from any efficiency loss. That is, the tradable performance standard can achieve the same (first-best) outcome as the cap-and-trade policy. However, a necessary condition for an equity-efficiency trade-off is that for a small (or zero) efficiency difference, equity effects are large enough that TPS should be preferred in a meaningful way. By focusing on the case of inelastic demand, we focus on just how large the equity concern might be. We can get a sense of how it might or might not overwhelm efficiency concerns without the parameterization and notational burden to measure that as well.

To see how this works, note that household  $i$ 's change in consumption of  $X$  under CAT is given by  $-Z_i(C(p_m) - C(0)) + s_i p_m M$ : that is, the added cost of buying the fixed electricity demand  $Z_i$  subtracted from the household's share of allowance value. As noted above, this consumption change is a measure of household utility change. Under a TPS, the change is given by  $-Z_i(C(p_m) - R p_m - C(0))$ . Hence the difference between the policy outcomes for household  $i$  is given by  $(s_i - Z_i/Z)p_m M$ , where we have used  $R = M/Z$  to simplify. This difference depends on whether the value of the household's share of the allowance revenues exceeds its share of electricity demand. Moreover,  $\sum_i (s_i - Z_i/Z) = 0$ . As noted before, with



**Figure 4. Emissions rents,  $b$ , compared with compliance costs,  $a$**

inelastic demand, aggregate costs are the same for both policies. In our notation, that cost is equal to  $Z(C(p_m) - C(0)) - Mp_m$ . That is, for CAT, cost per unit of energy is higher because of the carbon price, but the emissions payments are offset by lump-sum rebates. The net effect of the embodied emissions costs is zero for the population as a whole but can be positive or negative for any particular household. In contrast, the tradable performance standard ensures that revenues are rebated directly per unit and go directly to those households who otherwise bear the most burden.

This distinction emphasizes two important questions that arise when thinking about the equity differences between CAT and TPS: (1) How large is the potential redistribution of rents,  $b$  (where  $b \equiv p_m M$  is the total emissions payments), compared with net cost to society,  $a$  (where  $a \equiv Z(C(p_m) - C(0)) - p_m M$  represents compliance costs in our simple model)? And (2) how different are the distributions (i.e., how might  $(s_i - Z_i/Z)$  vary) across households?

Figure 4 illustrates how we might think about the relative magnitudes of  $a$  and  $b$ . In this linear marginal abatement cost example,  $a$  is a triangle and  $b$  is a rectangle. Abatement has to be twice as large as remaining emissions for the triangle  $a$  to be as large as the rectangle  $b$ . Thus, for modest mitigation policies,  $b \gg a$ : the rents created by the policies tend to be much larger than the actual costs of reducing emissions.

This intuition is borne out in existing analyses of CAT or TPS policies that compare the magnitude of allowance value against net societal costs. We earlier noted the work by Burtraw and Palmer (2008) examining a modest proposal that would have entailed net costs of \$0.5 billion and \$21 billion in allowance value. The Energy Information Administration (2009) analysis of the Waxman-Markey bill (H.R. 2454), for example, estimated total costs of \$50 billion in 2020 and allowance value of \$170 billion. The US Environmental Protection Agency (2009) analysis of the same bill estimated costs of \$30 billion in 2020 and allowance value of \$80 billion. Both of these approaches suggest that for policies that are modestly or moderately stringent, allowance value will be several times the size of the net cost to society.

The second question is more difficult. Most proposed reforms (e.g., Baker III et al. 2017) suggest  $s_i$  might be a per capita refund or could be connected to income through a cut to income or social security taxes. As an example of the latter, Dinan (2012) examines individual income tax cuts, per household or per capita rebates, payroll tax cuts, and increases in spending for low-income programs. Metcalf (1999, 2008) considers payroll and income tax cuts. Mathur and Morris (2014) consider returning allowance value through a combination of corporate or personal income tax cuts. Cronin et al. (2017) consider three scenarios: a per capita rebate, a proportional increase in current programs, and a cut to payroll taxes or an increase in social security benefits. Goulder and Hafstead (2017) analyze a suite of revenue-neutral carbon taxes

and examine the economy-wide and distributional effects (across five income quintiles) of per household rebates, payroll tax cuts, individual income tax cuts, and corporate income tax cuts. They also consider hybrid rebate–individual tax cut and rebate–corporate tax cut policies designed to keep the lowest income quintiles unharmed by climate policies. Though not exhaustive, these examples suggest a natural assumption that, to the extent rebates vary across household,  $s_i$  would be tied to household income or family size, possibly in a nonlinear way.

### ***Household data***

We now turn to parameterizing our stylized CAT and TPS policies, requiring data on both households and policy parameters. We can then determine the effects on individual households and consider how different welfare metrics and summary statistics would indicate aggregate inequality. Under the assumptions discussed earlier, effects on individual households can be summarized based on their change in electricity expenditures plus any allowance value rebate due to each policy.

To provide a basis for likely variation in consumption of electricity and other demographics necessary for these calculations, we use US consumer expenditure data. In particular, we turn to the 2014 Consumer Expenditure Survey, or CEX (BLS 2014). This is a rolling, quarterly survey, where a representative sample of US households enters each quarter and remains in the survey for five quarters. We compute the total expenditure on electricity and total expenditures overall for the calendar year. We include only survey respondents who participated for the entire year (1,036). That is, we first match household respondents on their household identifier for each quarter of 2014 and keep only those households observed for all

**Table 1. Summary statistics for numerical exercise**

	observations	mean	Std. dev.	Min	Max
Electricity	1,086	1,037	844	0	5,907
Log(Electricity)	1,036	6.72	0.764	3.64	8.68
Expenditures	1,086	35,936	32,518	1902	330,237
Log(Expenditures)	1,086	10.2	0.821	7.55	12.71

four quarters. We sum reported expenditures on electricity over these four quarters, as well as total expenditures.<sup>7</sup> Table 1 summarizes the data.

This provides the grist for our hypothetical policies, in the form of a two-dimensional distribution of electricity consumption and income (and possibly other demographics) across households. With the assumption that electricity demand is completely inelastic, we need only to specify the assumed regulatory costs and rents per household,  $a/N$  and  $b/N$ , along with a policy choice about  $s_i$  to calculate household incidence. That is, the TPS incidence is given by

$-\left(\frac{a}{N}\right)\left(\frac{Z_i}{\bar{Z}}\right)$  and the CAT incidence is given by  $-\left(\frac{a}{N} + \frac{b}{N}\right)\left(\frac{Z_i}{\bar{Z}}\right) + \left(\frac{s_i}{\bar{s}}\right)\left(\frac{b}{N}\right)$ , where  $\bar{Z} = Z/N$  and

$\bar{s} = 1/N$ . We assume household  $i$ 's share of total electricity,  $Z_i/Z$ , is given by its share of total electricity expenditures in the data.

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<sup>7</sup> Total expenditures (TOTEXPPQ) include all outlays by households for goods and services as well as contributions to pensions.

For expositional purposes, we fix  $s_i = 1/N$ —that is, equal per household rebates. This simple assumption is consistently suggested in various carbon pricing schemes (Inglis 2009; Larson 2015; Blumenauer 2017; Baker III et al. 2017).

Given our interest in inequality, it is natural to ask how much better we could do in terms of reducing the variation  $(s_i - Z_i/Z)$  across households in terms of a more targeted rebate. We know that electricity expenditures vary with household size and income, among other observed variables. We explored exactly this question by taking our data from the CEX and trying to predict electricity expenditures. More precisely, we took all of the household characteristics contained in the CEX interview survey, converted categorical variables to indicators, and replaced missing geographic identifiers with zeros.<sup>8</sup> This resulted in a set of 133 variables. With this enhanced data set, we had 879 complete observations (of 1,036 original observations). We then used the LASSO algorithm with cross-validation to choose the best predictive model that is robust to concerns about multiple hypothesis tests (James et al. 2013). We find 35 variables, including total expenditures, useful in predicting electricity use.<sup>9</sup> As summarized in Figure 1, however, all of these variables predict about half of total variation in electricity use (R-squared of 0.56), leaving considerable residual variation. Although we may overstate the variation and potential equity cost of carbon pricing, any approach that meaningfully addresses such concerns would not alter the basic point that we make and its general magnitude.

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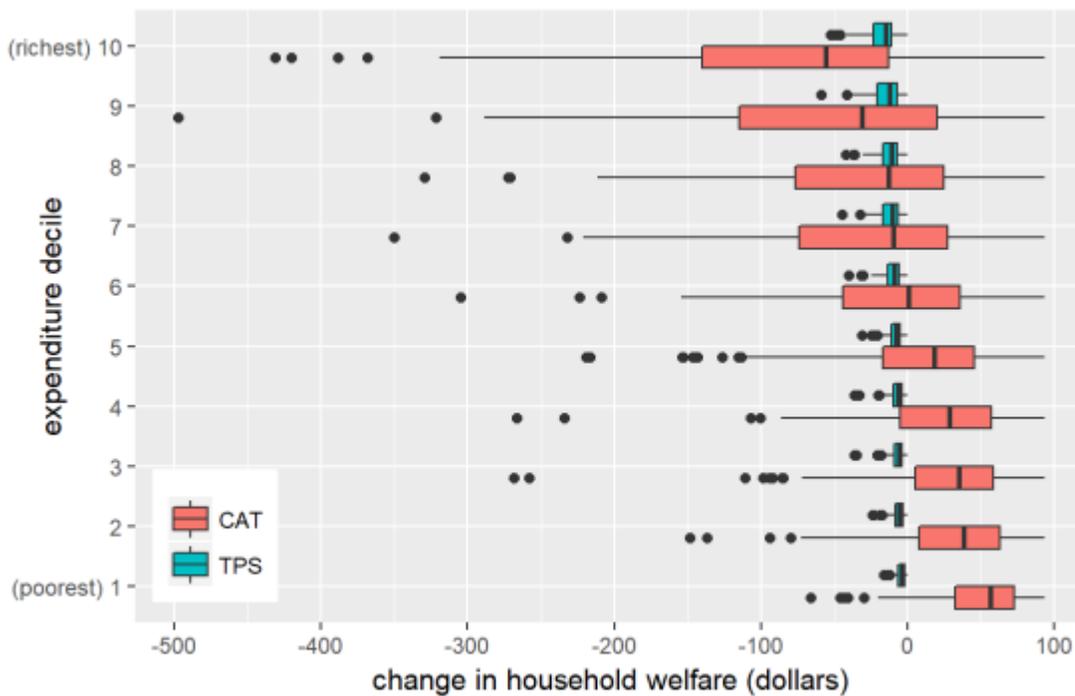
<sup>8</sup> This includes all variables listed as “Consumer Unit (CU) Characteristics” in the data dictionary. For many observations, geographic identifiers are omitted to protect confidentiality in the public-use data sets. For our purposes, available identifiers (e.g., 0/1 variables for particular states or PSUs) can be useful predictors and missing values simply become a reference group where we do not know the location.

<sup>9</sup> This includes 19 geographic identifiers (2 regional indicators, 9 state indicators, and 8 PSU indicators), 6 income variables (log expenditures, 2 rank variables, INC\_RANK and ERANKHM, and 3 income category indicators), 4 family size and age variables (family size, 1 indicator for all children >17 years, 2 family type indicators), and 6 variables describing the housing location (2 population size indicators, a rural-urban indicator, and 2 indicators of housing tenure).

**Table 2. Hypothetical policies for numerical analysis**

	Effect on household $i$
Tradable performance standard (TPS)	$-(a/N)(Z_i / \bar{Z})$
Cap-and-trade with per household rebate	$-(a/N)(Z_i / \bar{Z}) - (b / N)(Z_i / \bar{Z} - 1)$

With these assumptions, Table 2 summarizes the main concepts for each policy and how they relate to underlying parameters and data. The TPS distributes the compliance costs according to electricity consumption shares, and the CAT policy adds a net emissions payment burden that is positive for households with above-average electricity consumption. The final step is to choose the average household-level parameters  $a/N$  and  $b/N$ . Based on recent analysis (EIA 2009), a reasonable assumption is that cap-and-trade regulation on carbon dioxide might raise electricity prices on the order of 10 percent. Based on other analysis (Burtraw and Palmer 2008), a reasonable assumption is that the actual cost (without the allowance revenue) is perhaps 10 percent of that (i.e., a 1 percent increase in electricity prices). Thus we choose  $a = 0.01$  times the average electricity expenditure in the sample and  $b = 0.09$  times that expenditure. Given the summary statistics in Table 1, we have  $a/N = \$10$  and  $b/N = \$93$ .



**Figure 5. Comparison of cap-and-trade (CAT) and tradable performance standard (TPS), in dollars**

***Estimated household effects and welfare metrics***

Figure 5 shows the effect of the two policies on household welfare based on the above assumptions. The mean household effect is  $-\$10$  for both policies. Because poorer households have smaller electricity expenditures, the per capita rebate under CAT leads to generally *positive* welfare effects for the lower half of the income distribution. However, some households even in the poorest decile—roughly one-quarter—remain worse off. Meanwhile, effects are all negative under the TPS but much smaller in magnitude.

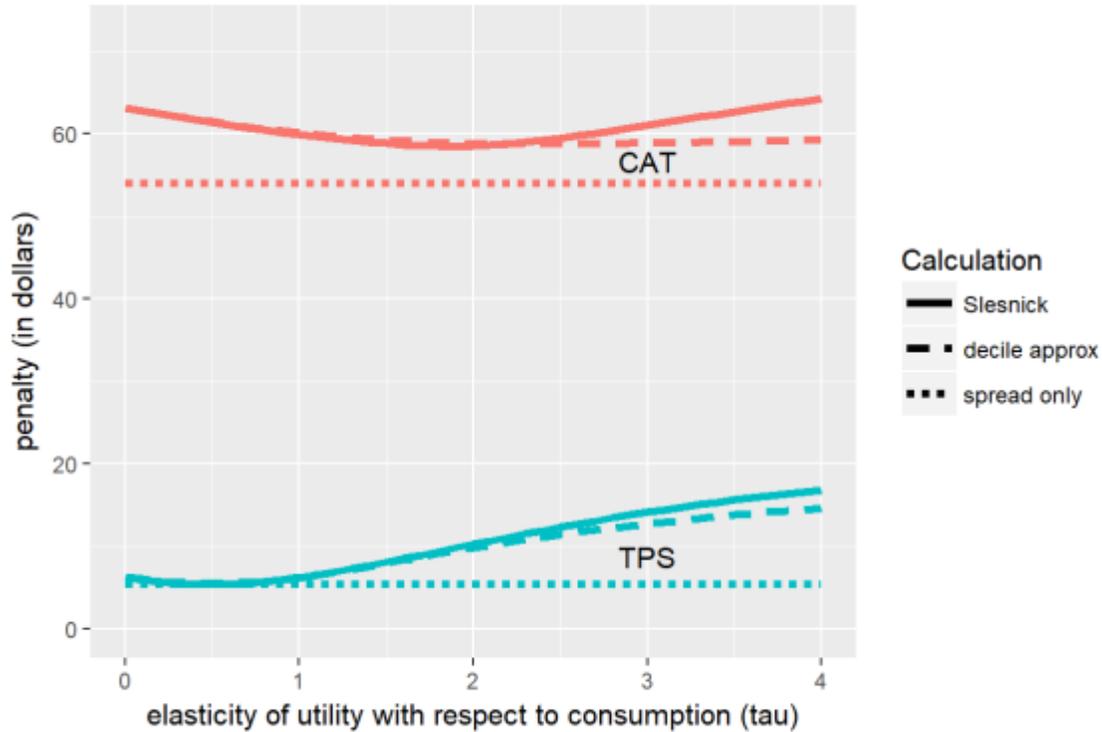
We observe at this point that most alternatives to a per capita rebate would vary the rebate by income. Such policies would shift the box plots for each expenditure decile but not change the spread within the decile. Basing rebates on other covariates could reduce the spread

within each decile, perhaps by a factor of two, as in Figure 1. But none of these alternatives would fundamentally change the distinction that CAT creates more within-decile variability than TPS.

Whether society should be concerned about this variability within expenditure decile depends on one's view about social welfare and burden sharing. Traditional social welfare functions, and even Auerbach and Hassett's, tend to be dominated by effects across deciles. That is, welfare calculations are largely determined by the extent to which a policy shifts income from the rich to the poor (whether intentionally or incidentally). Theories that promote some notion of a fair share of policy costs rather than redistribution, however, will be concerned with this within-decile variation.

We showed that both prospect theory and Slesnick (1989) can motivate a social welfare measure of the form  $\overline{\Delta y} - \gamma N^{-1} \sum |\Delta y_i - r_i|$ , where  $r_i$  is the fair burden for household  $i$  and  $\gamma$  is the relative importance of inequality versus. Slesnick argues for basing fair burden on an equal change in utility among all households. In that case,  $r_i \propto (u'(y_i))^{-1}$ . That is, each household's fair burden is proportional to the inverse of its marginal utility of income. As shown in Figure 2, this leads to a fair burden rising or falling as a share of income, depending on whether the elasticity of utility with respect to consumption,  $\tau$  in (3), is greater or less than 1. In all cases, the dollar burden rises with income so long as  $\tau > 0$ .

Figure 6 shows how different notions of fair burden, calculated with different values of  $\tau$  in (3), lead to different penalty factors,  $N^{-1} \sum |\Delta y_i - r_i|$ . The solid lines in Figure 6 represent the exact fair burden ("Slesnik"), given by  $r_i = b \times (u'(y_i))^{-1} / \sum_j (u'(y_j))^{-1}$ . This is the cost burden that yields an identical change in utility,  $b \left( \sum_j (u'(y_j))^{-1} \right)^{-1}$ , across households. The



**Figure 6. Effect of varying utility curvature / risk aversion parameter  $\tau$  on inequality penalty**

dashed lines show what happens when we approximate the fair burden reference points by decile; that is,

$$r_i^d = b \times \left( u'(\bar{y}_{d(i)}) \right)^{-1} / \sum_j \left( u'(\bar{y}_{d(j)}) \right)^{-1}. \quad (5)$$

This exercise highlights whether statistics based on decile measures might be a reasonable approximation, as discussed below. Finally, the dotted lines show the penalty that arises from setting the fair burden reference point as the average within-decile change (“spread only”):

$$r_i = \Delta \bar{y}_{d(i)}. \quad (6)$$

This last reference point calculation allows us to see how much penalty arises solely from within-decile variation. The horizontal axis indicates the value of  $\tau$ , and the vertical axis, the penalty, with solid red for CAT and solid blue for TPS.

CAT clearly faces a higher penalty for inequity across all metrics—on the order of \$60, versus \$10 for TPS. Compare this with the average burden,  $a/N = -\$10$ . Both penalties initially decrease as  $\tau$  rises, and then increase for sufficiently large  $\tau$ . Although our example of fixed demand assumed away efficiency costs of a TPS, the fact is that any such efficiency costs tend to be less than the primary compliance costs.<sup>10</sup>

This pattern arises because the penalty depends on both (1) how the typical burden at a given income level,  $E[\Delta y|y]$ , compares with the fair burden determined by  $\tau$ , and (2) the variability of the burden conditional on income, which increases the penalty regardless. Regarding the first point, there is a value of  $\tau$  where the fair burden most closely matches each policy's distribution over income levels and the penalty is minimized. This is  $\tau \sim 0.5$  for the TPS and  $\tau \sim 2$  for the CAT, reflecting the fact that CAT plus dividend is more progressive. That is, the burden of TPS is less than proportional to income, whereas the burden of CAT is more than proportional. Minimizing the penalty at  $\tau \sim 1$  would result in a burden exactly proportional to income. Regarding the second point, there is a baseline penalty level arising from variability at every income level that is higher for larger electricity price increases, which is why CAT penalties are uniformly higher.

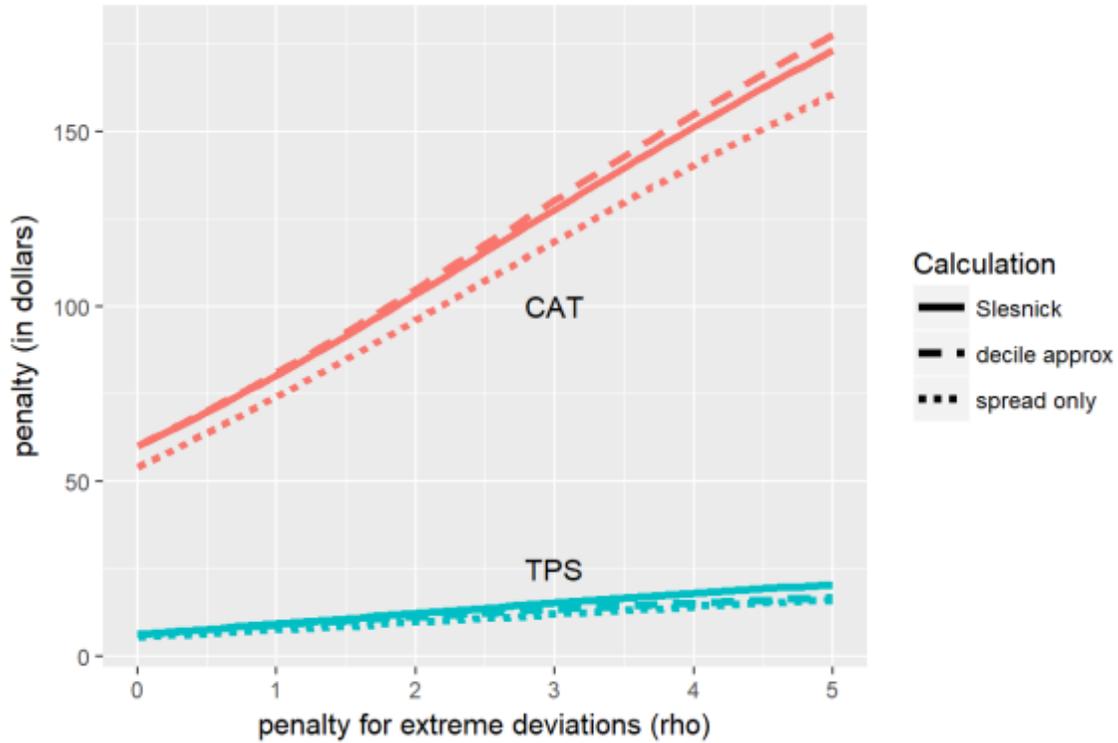
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<sup>10</sup> Fischer and Newell (2008) calculate a TPS as 41 percent more costly than CAT for a modest reduction target in the electricity sector; this estimate rises with more elastic demand and falls with more stringent targets. Fischer et al. (2017), in an updated extension, find the TPS just 14 percent more costly than CAT in their central scenario.

The decile-based distribution of burden in Figure 5 can be used both to approximate the exact Slesnick calculation and to help provide a decomposition, a calculation represented by the dashed lines in Figure 6. Here,  $d(i)$  is the decile (1–10) associated with observation  $i$ , and  $\bar{y}_{d(i)}$  is the average income in that decile. Generally, the approximation works well until  $\tau$  exceeds 2–3. At such a high level of utility curvature, there is a significant emphasis on differentiating *within* deciles, particularly the richest one.

Knowing the decile approximation is reasonable, we can now look at how much of the penalty variability occurs within the decile. The dotted lines in Figure 6 show the calculation of  $N^{-1}\sum|\Delta y_i - \Delta \bar{y}_{d(i)}|$ ; that is, we simply look at within-decile variation. If we were able to make arbitrary redistributions based on income alone, this would be the leftover penalty. It is also the contribution that can be easily calculated based on the data in Figure 5 without any assumptions about utility (note it does not depend on  $\tau$ ). We see that most of the penalty comes from the variability until  $\tau > 1$ , and the bulk of the difference between CAT and TPS is driven by this variability.

Finally, we examine how the penalty varies with the parameter  $\rho$  in the Slesnick model. That is, we examine  $(N^{-1}\sum|\Delta y_i - r_i|^{1+\rho})^{\frac{1}{1+\rho}}$  for different values of  $\rho$ . From the earlier discussion, we know that higher values of  $\rho > 0$  increasingly tilt the penalty expression toward the value of the highest absolute deviation. Figure 7 shows this pattern for the CAT and TPS policies (solid lines), assuming  $\tau = 1$  (log utility), and we see that pattern. The penalty is roughly double for  $\rho = 4$  versus  $\rho = 0$ . Like Figure 6, the figure also shows the values of the penalty expression when we (a) use decile approximations  $r_i$  (dashed lines) based on (5), and (b) examine the penalty attributable only to the spread within each decile based on (6) (dotted lines).



**Figure 7. Effects of varying inequality parameter  $\rho$  on inequality penalty**

Here, we see that the decile approximation makes no difference with respect to  $\rho$ , and that the spread of effects within deciles dominates the inequality penalty.

Our main presentation of welfare results has been graphical, in the form of Figure 5. It is also possible to present results in tabular form. For  $\rho = 1$ , the penalty equals the standard deviation of the household effects. Along with  $\rho = 0$ , where the penalty equals the average absolute deviation, it is relatively easy to numerically present summary statistics for at least two values of  $\rho$  in a table of summary decile values. This information is illustrated in Table 3, where we provide the average income and fair burden, based on  $\tau = 1$ , by decile. For the TPS and CAT policies, we then show the average burden by decile along with the two measures of spread within decile relevant for  $\rho = 0$  (avg ||) and  $\rho = 1$  (std. dev.). As highlighted in Figure 6 and

**Table 3. Summary statistics for horizontal and vertical welfare effects (\$) from cap-and-trade (CAT) versus tradable performance standard (TPS)**

decile	avg. income	fair burden ( $\tau = 1$ )	CAT effect			TPS effect		
			avg.	avg.	std. dev.	avg.	avg.	std. dev.
10	108,100	-31.2	-84.5	84.5	107.7	-17.8	8.4	10.8
9	60,900	-17.6	-59.4	78.9	102.5	-15.3	8.0	10.2
8	46,100	-13.3	-33.5	61.8	79.7	-12.7	6.2	8.0
7	36,600	-10.6	-32.7	62.5	82.4	-12.6	6.4	8.2
6	29,300	-8.5	-13.5	51.7	69.5	-10.7	5.2	7.0
5	23,500	-6.8	2.3	52.7	67.6	-9.1	5.0	6.8
4	19,100	-5.5	16.6	51.6	60.0	-7.7	4.3	6.0
3	15,300	-4.4	21.7	52.9	61.6	-7.1	4.2	6.2
2	11,300	-3.3	30.8	49.8	47.4	-6.2	3.6	4.7
1	6,400	-1.9	47.9	54.2	34.4	-4.3	2.7	3.4
avg.	35,900	-10.4	-10.4	60.3	81.0	-10.4	5.4	7.4

Figure 7, the measures of spread within deciles dominate the penalty expression. The average values across deciles (\$54 and \$74 for CAT, and \$5 and \$7 for TPS) match the  $\rho = 0$  and  $\rho = 1$  values for spread in Figure 7, highlighting how summary statistics by decile closely relate to the fair burden notions that we have discussed. Additional information about the distribution of household burden within decile (e.g., the box plots in Figure 7) can be used to extrapolate the penalty value for other values of  $\rho$ , as the penalty is increasingly driven by larger deviation values. One could also consider how different values of  $\tau$  suggest alternative fair burdens, and/or present results in terms of percentage of income rather than dollar terms.

## Conclusion

Our principal motivation has been to highlight that Pigouvian taxes in the energy sector may have large and often overlooked distributional consequences. In particular, they tend to raise energy prices and lead to greater variation in household-level effects *within* income groups. These consequences are difficult to remedy through typical redistribution schemes. Other policies to reduce pollution can have smaller effects on energy prices, and hence smaller distributional consequences, even as they have higher aggregate costs to society.

Should this variation in household costs within income groups matter? Traditional welfare notions tend to focus on overall costs to society. Distributional effects matter to the extent that they change the underlying income distribution and make it more or less equitable. That is, transfers from rich to poor are welfare-improving regardless of overall costs. In this paper, we have highlighted the notion of fair burden as an alternative to traditional welfare notions. Fair burden emphasizes how the cost of a public good should be shared across households, typically based on income, *without* an implicit welfare reward for redistribution from rich to poor. The fair burden approach places special emphasis on the current distribution of income, which we have shown can arise either by positing such a welfare measure (Slesnick 1989) or based on the observed importance of reference points (Kahneman and Tversky 1979). Both theories lead to a penalty based on the scale of deviations from the reference point or fair burden.

We applied these ideas to the comparison of two policy options that have been proposed to address carbon dioxide emissions in the electricity sector—cap-and-trade (CAT) and tradable performance standards (TPS). In modeling the stylized implications of these two alternatives, we highlighted that deviations from fair burden comprise (1) average deviations from fair burden

across income levels (similar to traditional welfare theory), and (2) variation in burden within each income level. Changes in income-based taxes have the potential to address the first component. The second is more difficult to avoid. By our assessment, at least half of the variation in burden appears to be unpredictable based on observed household demographics.

In our application, we showed how to use summary statistics to describe the inequality penalty associated with fair burden. We specifically considered measures by decile of mean burden, average absolute deviation, and standard deviation, as well as a visual presentation of the cost distribution by decile. These measures provide a practical and intuitive way to communicate the distribution of household costs relevant for theoretical notions of fair burden. Such an approach is analogous to the use of Lorenz curves and Gini coefficients to describe the income inequality associated with traditional welfare notions.

Our specific example shows that the inequality penalty from a traditional CAT program can be several times that of a TPS and several times the actual compliance costs. The higher CAT penalty follows directly from the larger consumer price increases under CAT versus TPS. The higher price increase leads to burdens for some households within each decile that are much larger under CAT versus TPS, and much larger than average per household compliance costs. Exactly how to weight this effect, visually depicted in Figure 5, is a question of ethics and societal preferences. However, the possibility that equity and distributional concerns could outweigh efficiency trade-offs may be something that politicians have known for some time, and that only analysts are now beginning to recognize.

## References

- Abbott, Joshua K., and Eli P. Fenichel. 2014. "Following the Golden Rule: Negishi Welfare Weights without Apology." [http://jkabbott.faculty.asu.edu/wp-content/uploads/golden\\_rule\\_7\\_13.pdf](http://jkabbott.faculty.asu.edu/wp-content/uploads/golden_rule_7_13.pdf).
- Adler, Matthew D. 2013. "The Pigou-Dalton Principle and the Structure of Distributive Justice." Working Paper. Duke University. [https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=2263536](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2263536).
- Auerbach, Alan J., and Kevin A. Hassett. 2002. "A New Measure of Horizontal Equity." *American Economic Review* 92 (4):1116–25. <https://doi.org/10.1257/00028280260344650>.
- Baker III, James A., Martin Feldstein, Ted Halstead, N. Gregory Mankiw, Henry M. Paulson Jr, George P. Shultz, Thomas Stephenson, and Rob Walton. 2017. "The Conservative Case for Carbon Dividends." The Climate Leadership Council. <https://www.clcouncil.org/>.
- Bingaman, Jeff. 2012. *S.2146 - 112th Congress (2011-2012): Clean Energy Standard Act of 2012*. <https://www.congress.gov/bill/112th-congress/senate-bill/2146>.
- Blumenauer, Earl. 2017. *H.R.3420 - 115th Congress (2017-2018): American Opportunity Carbon Fee Act of 2017*. <https://www.congress.gov/bill/115th-congress/house-bill/3420/text>.
- Boyce, Christopher J., Gordon D.A. Brown, and Simon C. Moore. 2010. "Money and Happiness: Rank of Income, Not Income, Affects Life Satisfaction." *Psychological Science* 21 (4):471–75. <https://doi.org/10.1177/0956797610362671>.
- Brown, Sarah, Daniel Gray, and Jennifer Roberts. 2015. "The Relative Income Hypothesis: A Comparison of Methods." *Economics Letters* 130 (May):47–50. <https://doi.org/10.1016/j.econlet.2015.02.031>.
- Bureau of Labor Statistics (BLS). 2014. "Consumer Expenditure Survey." 2014. <https://www.bls.gov/cex/>.
- Burtraw, Dallas, David A. Evans, Alan Krupnick, Karen Palmer, and Russell Toth. 2005. "Economics of Pollution Trading for SO<sub>2</sub> and NO<sub>x</sub>." *Annual Review of Environment and Resources* 30 (1):253–89. <https://doi.org/10.1146/annurev.energy.30.081804.121028>.
- Burtraw, Dallas, and Karen Palmer. 2008. "Compensation Rules for Climate Policy in the Electricity Sector." *Journal of Policy Analysis and Management* 27 (4):819–47. <https://doi.org/10.1002/pam.20378>.
- Clark, Andrew E., and Andrew J. Oswald. 1994. "Unhappiness and Unemployment." *The Economic Journal* 104 (424):648. <https://doi.org/10.2307/2234639>.
- Cohen, Richard E. 1995. *By Richard E. Cohen - Washington at Work: Back Rooms and Clean Air: 2nd (Second) Edition*. Longman.
- Cronin, Julie Anne, Don Fullerton, and Steven E. Sexton. 2017. "Vertical and Horizontal Redistributions from a Carbon Tax and Rebate." Working Paper 23250. National Bureau of Economic Research. <https://doi.org/10.3386/w23250>.

- Dinan, Terry. 2012. "Offsetting a Carbon Tax's Costs on Low-Income Households." Working Paper 2012–16. Congressional Budget Office. <https://www.cbo.gov/publication/43713>.
- Duesenberry, James S. (James Stemble). 1949. *Income, Saving, and the Theory of Consumer Behavior*. Cambridge, Harvard University Press, 1949. <br />: Harvard University Press,.
- Elkins, David. 2006. "Horizontal Equity as a Principle of Tax Theory." *Yale Law & Policy Review* 24 (1):43–90.
- Energy Information Administration (EIA). 2009. "Energy Market and Economic Impacts of H.R. 2454, the American Clean Energy and Security Act of 2009." <https://www.eia.gov/analysis/requests/2009/hr2454/>.
- Fischer, Carolyn, and Alan K. Fox. 2007. "Output-Based Allocation of Emissions Permits for Mitigating Tax and Trade Interactions." *Land Economics* 83 (4):575–99. <https://doi.org/10.3368/le.83.4.575>.
- Fischer, Carolyn, and Richard G. Newell. 2008. "Environmental and Technology Policies for Climate Mitigation." *Journal of Environmental Economics and Management* 55 (2):142–62.
- Fischer, Carolyn, Louis Preonas, and Richard G. Newell. 2017. "Environmental and Technology Policy Options in the Electricity Sector: Are We Deploying Too Many?" *Journal of the Association of Environmental and Resource Economists* 4 (4):959–84. <https://doi.org/10.1086/692507>.
- Goulder, Lawrence, and Marc Hafstead. 2017. *Confronting the Climate Challenge: U.S. Policy Options*. Columbia University Press.
- Inglis, Bob. 2009. *Raise Wages, Cut Carbon Act of 2009*. <https://www.congress.gov/bill/111th-congress/house-bill/2380/text>.
- James, Gareth, Daniela Witten, Trevor Hastie, and Robert Tibshirani. 2013. *An Introduction to Statistical Learning: With Applications in R*. 1st ed. 2013, Corr. 7th printing 2017 edition. New York: Springer.
- Kahneman, Daniel, and Amos Tversky. 1979. "Prospect Theory: An Analysis of Decision under Risk." *Econometrica* 47 (2):263–291.
- Kaplow, Louis. 1989. "Horizontal Equity: Measures In Search Of A Principle." *National Tax Journal* 42 (2):139–54.
- Kőszegi, Botond, and Matthew Rabin. 2006. "A Model of Reference-Dependent Preferences." *The Quarterly Journal of Economics* 121 (4):1133–1165.
- . 2007. "Reference-Dependent Risk Attitudes." *The American Economic Review* 97 (4):1047–1073.
- . 2009. "Reference-Dependent Consumption Plans." *American Economic Review* 99 (3):909–36. <https://doi.org/10.1257/aer.99.3.909>.
- Larson, John. 2015. *H.R.3104 - 114th Congress (2015-2016): America's Energy Security Trust Fund Act of 2015*. <https://www.congress.gov/bill/114th-congress/house-bill/3104/text>.

- Mathur, Aparna, and Adele C. Morris. 2014. "Distributional Effects of a Carbon Tax in Broader U.S. Fiscal Reform." *Energy Policy* 66 (March):326–34. <https://doi.org/10.1016/j.enpol.2013.11.047>.
- Metcalf, G. E. 2008. "Designing a Carbon Tax to Reduce U.S. Greenhouse Gas Emissions." *Review of Environmental Economics and Policy* 3 (1):63–83. <https://doi.org/10.1093/reep/ren015>.
- Metcalf, Gilbert E. 1999. "A Distributional Analysis of Green Tax Reforms." *National Tax Journal* 52 (4):655–681.
- Michaelson, Zachary. 2015. "Biases in Choices about Fairness: Psychology and Economic Inequality." *Judgment and Decision Making* 10 (2):198.
- Mill, John Stuart. 1871. *Utilitarianism*. Longmans, Green, Reader, and Dyer.
- Mueller, Dennis C. 2003. *Public Choice III*. 3 edition. Cambridge ; New York: Cambridge University Press.
- Negishi, Takashi. 1960. "Welfare Economics and Existence of an Equilibrium for a Competitive Economy." *Metroeconomica* 12 (2–3):92–97. <https://doi.org/10.1111/j.1467-999X.1960.tb00275.x>.
- Neilson, William, and Jill Stowe. 2002. "A Further Examination of Cumulative Prospect Theory Parameterizations." *Journal of Risk and Uncertainty* 24 (1):31–46.
- Nowaihi, Ali al-, Ian Bradley, and Sanjit Dhami. 2008. "A Note on the Utility Function under Prospect Theory." *Economics Letters* 99 (2):337–39. <https://doi.org/10.1016/j.econlet.2007.08.004>.
- Pigou, A. C. 1928. *A Study in Public Finance*. Macmillan.
- Poterba, James M. 1991. "Is the Gasoline Tax Regressive?" *Tax Policy and the Economy* 5:145–64.
- Prelec, Drazen. 1998. "The Probability Weighting Function." *Econometrica* 66 (3):497–527. <https://doi.org/10.2307/2998573>.
- Quiggin, John. 1993. *Generalized Expected Utility Theory - The Rank-Dependent Model*. Springer. [//www.springer.com/gp/book/9780792393023](http://www.springer.com/gp/book/9780792393023).
- Rausch, Sebastian, Gilbert E. Metcalf, and John M. Reilly. 2011. "Distributional Impacts of Carbon Pricing: A General Equilibrium Approach with Micro-Data for Households." *Energy Economics*, Supplemental Issue: Fourth Atlantic Workshop in Energy and Environmental Economics, 33, Supplement 1 (December):S20–33. <https://doi.org/10.1016/j.eneco.2011.07.023>.
- Simons, Henry C. 1938. *Personal Income Taxation: The Definition of Income As a Problem of Fiscal Policy*. First Edition edition. Chicago, Ill.: The University of Chicago Press.
- Slesnick, Daniel T. 1989. "The Measurement of Horizontal Inequality." *The Review of Economics and Statistics* 71 (3):481–90. <https://doi.org/10.2307/1926905>.
- Thaler, Richard. 1980. "Toward a Positive Theory of Consumer Choice." *Journal of Economic Behavior & Organization* 1 (1):39–60.

- Tversky, Amos, and Daniel Kahneman. 1992. "Advances in Prospect Theory: Cumulative Representation of Uncertainty." *Journal of Risk and Uncertainty* 5 (4):297–323.
- US EPA. 2009. "EPA Analysis of the American Clean and Security Act of 2009 HR 2454 in the 111th Congress." <https://www.c2es.org/federal/congress/111/acesa>.
- Waxman, Henry. 2009. *H.R.2454 - 111th Congress (2009-2010): American Clean Energy and Security Act of 2009*. <https://www.congress.gov/bill/111th-congress/house-bill/2454/text>.
- Weinzierl, Matthew C. 2012. "Why Do We Redistribute so Much but Tag so Little? The Principle of Equal Sacrifice and Optimal Taxation." NBER Working Paper 18045. National Bureau of Economic Research, Inc. <https://ideas.repec.org/p/nbr/nberwo/18045.html>.
- Westort, Peter J., and Janet M. Wagner. 2002. "Toward a Better Measure of Horizontal Equity." *Journal of the American Taxation Association* 24 (1):17.
- World Bank, Ecofys, and Vivid Economics. 2016. *State and Trends of Carbon Pricing 2016*. Washington, DC: World Bank.

## Appendix: A simple model of electricity production, demand, and pollution

Consider a simple economy with two goods,  $Z$  and  $X$ . Think of the goods as electricity and everything else, respectively. For simplicity, we assume a population of  $N$  households that are endowed with different amounts of  $X$  indicated by  $X_i^0$ . Moreover, each household has different preferences over  $Z$  and  $X$  summarized by  $U_i(Z, X)$ . Electricity is produced using both  $X$  and emissions  $M$  through a constant-returns-to-scale technology defined by the unit cost function  $C(p_x, p_m)$ , where  $p_x$  and  $p_m$  are the input prices for  $X$  and  $M$ , respectively. That is, it is the unit cost associated with having to buy  $X$  and  $M$  to produce electricity in the least cost way, assuming cost minimization within the electricity sector and prices  $p_x$  and  $p_m$ . Without loss of generality, we let  $X$  be the numeraire,  $C(1, p_m) = C(p_m)$ , and  $e_i(p_z, U_i)$  is the expenditure function. That is, it is the cost of buying the cheapest combination of  $X$  and  $Z$  to achieve  $U_i$ , given prices  $p_z$  (and  $X$  being the numeraire). The derivative of the expenditure function gives household demand for electricity,  $z_i(p_z, U_i)$ , and the derivative of the cost function gives unit demand for pollution  $m(p_m)$ .

This formulation captures the features we want to emphasize—and very little more. In particular, households differ from one another in terms of both wealth (e.g.,  $X_i^0$ ) and, even conditioning on wealth, their consumption of energy versus other goods. There is only one factor of production, so there are no source-side distribution effects outside the initial endowment.

Consider an initial equilibrium (superscript 0) with no constraint on  $M$ . This is the equilibrium that occurs when each household maximizes its utility subject to its endowment while electricity is produced in a cost-minimizing way.

By construction

$$\begin{aligned}
p_z^0 &= C(0) \\
X_i^0 &= e_i(p_z^0, U_i^0) \\
Z &= \sum Z_i(p_z^0, U_i^0)
\end{aligned}$$

Now consider a cap on pollution  $M$ . That is, imagine implementing a cap-and-trade policy in the electric power sector with cap  $M$ . We now have the added constraint that

$$m(p_m^C)Z = M$$

and added endogenous variable  $p_m$ . The unit price of electricity under the cap (superscript  $C$ ) reflects the increased cost of the pollution input:

$$p_z^C = C(p_m^C) \quad (7)$$

Payments for emissions rights represent a new endowment in the economy that we assign to households. That is, household  $i$ 's wealth now includes a share  $s_i$  of the allowance revenues, leading to the remaining equilibrium conditions:

$$\begin{aligned}
X_i^0 + s_i p_m^C M &= e_i(p_z^C, U_i^C) \\
Z &= \sum Z_i(p_z^C, U_i^C)
\end{aligned}$$

Now consider a rate-based regulation (superscript  $R$ ), where the emissions intensity of electricity ( $M/Z$ ) cannot exceed a regulated rate,  $R$ , or  $M \leq R \times Z$ . When implemented as a tradable performance standard, electricity generators continue to surrender permits based on emissions. However, they receive an allocation  $R$  based on their production of electricity that can be viewed as a rebate. Thus, the unit cost to households is

$$p_z^R = C(p_m^R) - p_m^R R \quad (8)$$

Comparing this with cap-and-trade, both entail direct compliance costs, but emissions pricing, like taxes or cap-and-trade, also imposes charges on the remaining emissions. Performance standards forgo these charges on embodied emissions, rebating their value. Tradable performance standards have the feature of equalizing emissions prices across regulated entities, while essentially forgiving the costs associated with an average rate of emissions (the performance standard). The implicit rebate is passed on to consumers in the form of smaller price changes, whereas cap-and-trade systems pass on the opportunity cost of emissions.

Electricity-related pollution lends itself particularly well to tradable performance standards because output is easy to measure, so regulations targeting tons per megawatt-hour are sensible. By focusing on tradable permits and tradable performance standards, we compare two policies that both feature marginal cost equalization within the power sector. This is implicit in the use of a cost function  $C(p_m)$ . However, these two policies, particularly applied to electricity regulation, highlight an important feature that concerns us: regulations that create significant rents that directly influence households, and those that do not.

The remaining equilibrium conditions are now given by

$$\begin{aligned} X_i^0 &= e_i(p_z^R, U_i^R) \\ Z &= \sum Z_i(p_z^R, U_i^R) \\ R &= m(p_m^R) \end{aligned}$$

Assuming they achieve the same emissions level,  $p_m^R \geq p_m^C$  and  $p_z^R < p_z^C$ . What happens if we start with the cap-and-trade prices  $p_m^C$  and  $p_z^C$  as possible solutions to the rate-based equations? From (7) and (8), we know that if  $p_m^R = p_m^C$ , then  $p_z^R < p_z^C$ . If  $p_z^R < p_z^C$ , we would typically expect  $Z^R > Z^C$  as households demand more electricity at a lower price. That would not continue to satisfy the same emissions target because, by definition,  $m(p_m) = M/Z$ . If  $Z$  is lower at a

given emissions price, emissions will be lower, too. Therefore, emissions prices rise under a tradable performance standard, and  $p_m^R > p_m^C$ , in order to hit the same emissions target under both policies. That same definition also makes it clear that even as emission prices rise,  $Z^R > Z^C$ , and it remains true that  $p_z^R < p_z^C$ .

Intuitively, pricing the emissions embodied in electricity encourages conservation and substitution away from electricity. Compared with the performance standard, cap-and-trade can achieve emissions reductions with less effort to reduce emissions intensity (see, e.g., Fischer and Fox 2007). The first inequality will be strict unless demand for  $E$  is completely inelastic. That is, if there is no demand response, the credit price in the tradable performance standard just rises to achieve the same abatement within the electricity generation process. Meanwhile, the electricity price increase must be lower under the tradable performance standard because of the implicit rebate.

In sum, a tradable performance standard will require a higher credit price to achieve the same emissions level because it does not raise the price of electricity as much—unless electricity demand is perfectly inelastic. When we assume electricity demand is fixed, the credit price will be the same under both policies. In this case, we can also redefine household utility as  $X_i$  given  $U_i(X, Z) = U_i(X, Z_i^0)$ . That is,  $X_i$  and  $U_i$  are now monotonic transformations of each other. Given  $X_i$  is the numeraire, we can further define utility as  $X_i = X_i^0 - p_z Z_i^0 + (rent)$ . Any change in utility can be measured as the change in expenditure on electricity plus any change in rents other than  $X_i^0$ . This is the approach we use in the body of the paper.

