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Horizontal Equity Effects in Energy Regulation

Carolyn Fischer, William A. Pizer

Abstract: Choices in energy regulation, particularly whether and how to price externalities, can have widely different distributional consequences both across and within income groups. Traditional welfare theory focuses largely on effects across income groups; such "vertical equity" concerns can typically be addressed by a progressive redistribution of emissions revenues. In this paper, we review alternative economic perspectives that give rise to equity concerns within income groups, or "horizontal equity," and suggest operational measures. We then apply those measures to a stylized model of pollution regulation in the electricity sector. In addition, we look for ways to present the information behind those measures directly to stakeholders. We show how horizontal equity concerns might overshadow efficiency concerns in this context.

JEL Codes: D61, D63, Q48, Q52, Q58

Keywords: equity, inequality, cap and trade, carbon price, performance standards

ECONOMISTS OFTEN GIVE PRIMACY to the efficiency or cost-effectiveness of regulatory design, favoring Pigouvian pricing mechanisms for addressing environmental externalities. Implicitly or explicitly, economists' favoritism assumes that equity concerns can be dealt with by allocating the rents created by emissions pricing. For example, tax rate changes can redistribute rents to achieve a desired level of progressivity across income groups, often with particular attention to outcomes for poor households.

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In this paper, we make three observations that together suggest that favoritism for Pigouvian policies may be misplaced because equity concerns are not so easily vanquished. First, the focus on equity as a question of effects across income groups, and the poor as a collective group, derives from traditional welfare theory, which places value on equalizing household utility and bringing the poor and rich closer together. However, an alternative line of thought, typically referred to as fair burden or horizontal equity (HE), places value on similar households' facing similar changes. The distribution of effects across income groups still matters but so do effects within income groups.

Second, Pigouvian pricing policies can involve household-level costs and benefits that are orders of magnitude larger than those arising under other, non-Pigouvian policies. This is true even as positive and negative household-level effects cancel out in the aggregate and Pigouvian policies are less expensive for society. Finally, the redistribution created by Pigouvian pricing of energy externalities can be substantially unrelated to income and other easily observable variables. This makes it difficult if not impossible to neutralize large, unequal effects within income groups.

Taken together, these observations suggest that Pigouvian energy regulation may have relatively large, unavoidable, horizontal equity effects and that economists' favoritism may be misplaced. It also raises a question: How can policy analysts present information about horizontal equity in ways that facilitate stakeholder discussion and policy maker decisions?

We note that this is not always the case. Some Pigouvian energy regulation does not directly affect households and equity effects are manageable. Under the acid rain program, for example, sulfur dioxide (SO_2) emissions from coal-fired power plants were capped at an agreed-upon level. With a general notion of how to allocate emissions rights, attention then shifted to horse trading among emitting companies to address the exact distribution of burden (Cohen 1995). But importantly, the price of electricity was largely unaffected (Burtraw et al. 2005). Natural gas generators are often the marginal producers and do not emit SO_2. Hence, power generation companies were the ones that felt the effects of the regulation and allocation choices—and were directly involved in those choices: Coasean bargaining at its best.

Market-based CO_2 programs, however, have the potential to raise electricity and other energy prices significantly. More than a hundred million households, as well as businesses, will feel the direct effect of regulation as well as the choices about allowance or revenue allocations. Direct horse trading to address equity is difficult if not impossible. Individual bargaining is replaced by generic rules, perhaps based on income or other observable demographics. As we show, it will be difficult to alleviate substantial inequity from energy price effects based on observable demographics.

Although our contribution ties energy regulation to policy-making concerns about horizontal equity, we are not the first paper to remark on these additional distributional effects of Pigouvian energy pricing. Burtraw and Palmer (2008) find that a carbon pricing policy has net social costs of roughly $0.5 billion annually, while consumers and producers lose more than $21 billion in pollution payments. With an eye toward fuel taxes, Poterba (1991) presents gasoline expenditures by income decile but also reports the fraction of each decile where expenditures shares are above 0.1 and where they are equal to zero. He finds an average share of 0.039 for the lowest decile, but 36% of this decile spend nothing on gasoline while 14% have an expenditure share exceeding 0.1. Among practitioners, analysis of tax reform proposals regularly focuses on the coefficient of variation of effects within income groups (Westort and Wagner 2002).

Taking a more expansive approach, Rausch et al. (2011) use graphical figures to present the distributional effects of carbon pricing associated with various rebate approaches. Their box-and-whisker plots, similar to our preferred graphical figures, show outcomes across and within income deciles. They highlight that some amount of progressivity and regressivity is certainly present, with the mean cost by decile ranging from 0% to 0.5% of income. At the same time, a large number of households experience gains and losses of more than 1%.

In a paper directly related to ours, Cronin et al. (2019, in this issue) consider a carbon tax paired with several alternative rebate mechanisms: a per capita rebate, an increase in the EITC, and cuts in payroll taxes coupled with increases in social security benefits. In their analysis, they pay particular attention to horizontal equity concerns: they find that the horizontal variation caused by various rebate schemes is larger than the variation caused by the carbon tax itself. Like Rausch et al., this variation is as large as, if not larger than, the differences in mean effects across deciles.

Beyond these noted papers, horizontal equity is largely ignored by economists writing about energy policy. Even those papers that characterize variation in household effects within income groups do not define an associated welfare cost. And only Burtraw and Palmer (2008) point out that non-Pigouvian policies can lead to much smaller distributional effects. In this way, we believe our paper offers a new perspective on efficiency-equity concerns.

To make our points about horizontal equity and Pigouvian pricing, we first review the various rationales for valuing horizontal equity as well as the controversies. We then present two welfare measures to operationalize these ideas and explain how they relate to models in the literature. To relate this to energy policy, we then turn to how energy regulation affects energy prices and ultimately household welfare. We consider a stylized model of two climate change policies. One policy is Pigouvian pricing, a mass-based cap-and-trade (CAT) policy applied to the electric power sector with auction revenue used to provide an equal rebate per household. The other is non-Pigouvian, a rate-based tradable performance standard (TPS) that is effectively a revenue-neutral combination of a tax on emissions and a subsidy to output of electricity. Thanks to the subsidy, the TPS does not raise electricity prices as much as the CAT.

To complete the task, we simulate the distributional consequences of these policies using a sample of observed consumer expenditures. Within this sample we see a large heterogeneity of household electricity expenditures even within a single income group.

The CAT therefore results in much more horizontal, within-income-group redistribution than the TPS. We put these outcomes into our welfare measure and show that this can translate into lower welfare under CAT versus TPS. Finally, we consider ways that one might present this information to stakeholders and policy makers without appealing to elaborate welfare theories while still remaining consistent with those theories. And we revisit the degree to which horizontal equity might be attenuated using other observable data, arguing that such efforts are unlikely to help.

1. FOUNDATIONS OF HORIZONTAL EQUITY IN ECONOMIC THOUGHT

Equity and justice have long been principles in public economics (Elkins 2006). Within this rich intellectual history, we identify two threads that speak to the idea of treating similar households similarly in public policy. An older literature frames the discussion in terms of equal sacrifice regarding the provision of public goods, and a more recent, welfarist approach builds on the axiomatic treatment of welfare measures. The latter encompasses both provision of public goods and redistribution from rich to poor. Beyond public economics, one can interpret the behavioral work by Tversky, Kahneman, and others as supporting horizontal equity. Here, we review these ideas before turning to operationalizing our approach.

1.1. Equal Sacrifice

The principle of equal sacrifice dates at least to the nineteenth century. For John Stuart Mill (1871, 155), "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 and to ensure that equally situated persons are treated equally. The nineteenth-century utilitarian philosopher and economist Henry Sidgwick (1883) considered equal sacrifice the "obviously equitable principle—assuming that the existing distribution of wealth is accepted as just or not unjust" (bk. III, chap. 7, sec. 1, para. 1). In other words, assuming that society does not want to engage in additional income redistribution, the burdens of financing government should be shared equally.

The question of whether society does or does not want to engage in income redistribution is an important distinction. This older literature tended to separate this question from the question of how to fund public goods. Tracing back to the Greeks, Elkins (2006, 73) argues that the principal of equal treatment can be seen as an application of Aristotelian philosophy, in which a just distribution is based on merit. If individuals "merit" their status quo ante distribution, then they should merit equal shares in the postintervention distribution. Of course, because the definition of merit matters for evaluating the fairness of Aristotelian justice, "the moral basis of horizontal equity depends upon the moral standing of the market distribution."

A second distinction framed in the early literature is the fair treatment of similar individuals versus the fair treatment of very different individuals. In a treatise on tax policy, Simons (1938, 106) states that "taxes should bear similarly upon persons similarly situated." Pigou himself noted that "equal sacrifice among similar and similarly situated persons is an entirely different thing from equal sacrifice among all persons" (Pigou 1928, pt. II, chap. 1, sec. 7).

1.2. Welfarism

The distinction between vertical and horizontal equity came to prominence in the early and mid-twentieth century, but it was the welfarists in the latter part of the twentieth century who introduced these terms. In that context, mitigating social inequality became referred to as "vertical equity" and treating people in similar circumstances similarly became recognized as "horizontal equity" (Elkins 2006, 43). Now, in addition to questions about taxes and the provision of public goods, social policy explicitly considered redistribution.

Welfarism looks at the desirability of public policy in terms of whether the state of affairs with the policy has a higher welfare measure than the state without (Sen 1979). A distinctive feature of horizontal equity is the comparison with a reference point, rooted in the status quo ante. Whereas vertical equity can be measured for any distribution of income or utility (such as with a Gini coefficient, before or after a policy intervention), assessing horizontal equity requires a change to evaluate. Similarly situated persons are so situated ex ante, and that reference point sits within a preexisting vertical distribution. Most traditional, axiomatic welfare measures (see chap. 23 of Mueller 2003) avoid reference points and fail to capture horizontal equity. Moreover, it is inclusion of a reference point that has regularly led to controversy.

Different approaches have been taken with respect to reference points. Early economic applications of horizontal equity in public finance focused on rank as a reference point. The Pigou-Dalton axiom holds that a social welfare function should prefer allocations that are more (vertically) equitable, as long as redistribution does not change the ranking of individuals. Adler (2013, 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."

A later application by Auerbach and Hassett (2002) introduces reference points by nesting groups with similar prepolicy incomes into an aggregate welfare function. Separate elasticity parameters penalize income inequality within the nested groups (horizontal equity) and across nested groups (vertical equity). Otherwise, the aggregate function looks like a more traditional welfare function of postpolicy outcomes, not changes. In practice, this makes it difficult to measure horizontal equity effects arising from a new policy when changes in income are small relative to existing differences between individuals within each nested group.[1] This is often the case with energy regulation.

In a series of articles, Kaplow (1989, 1992, 2000) critiques both applications and the underlying principles of horizontal equity. He is particularly critical of operationalizing the early focus on rank, where large rank-preserving redistributions would have to be compared with infinitesimal rank-inverting redistributions. The implied idea of large discontinuities in a welfare measure is unappealing. But he is more generally critical of the notion of a valid reference point, which he considers counter to the idea of economic mobility. He suggests that the status quo as a reference point arbitrarily treats policy outcomes as more significant than the "luck" leading to status quo differences. Moreover, once a policy is implemented, it becomes the status quo. If a policy has negative HE consequences, so does reversing the policy. He points out that HE implies a trade-off with the Pareto principle. Even if no one is worse off, there may be unequal treatment of similar households (though we show that this need not alter Pareto welfare rankings). Although it is beyond the scope of this paper to respond to all of Kaplow's criticisms—criticisms that we view as pointing out logistical consequences but not being fatal to the idea of HE in any case—there is certainly evidence that people think in terms of reference points.

1.3. Behavioral Economics

Distinct from the philosophical origins of horizontal equity, behavioral economics provides another motivation for believing reference points are important. In particular, 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 decision making. 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 included 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 decision making under uncertainty (and also includes concepts related to biases in evaluating high-risk, low-probability events), Michaelson (2015, 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."

1. Auerbach and Hassett remark that the horizontal equity effects of income taxes are equivalent to an across-the-board 0.2% to 0.4% tax increase—roughly a fraction 1/100 of total tax costs.

Thus, reference point biases offer additional support for considering aspects of horizontal equity in policy making.

1.4. Applications to Energy and Environmental Policy

There is reason to believe that horizontal equity issues can loom much larger than vertical equity ones for environmental policy. First, broad-based tax policy is the government's primary tool for addressing vertical inequality; environmental policy is an indirect one at best. 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, the goal is equal sacrifice relative to the status quo. Second, environmental policy costs tend to be small compared with income and other taxes but highly heterogeneous. In the application we consider, the effects are on the order of tens or hundreds of dollars per household.[2] Such changes are unlikely to affect vertical equity in a meaningful way. Nonetheless, equity and fairness concerns remain in the same way that overall cost-benefit concerns remain. And although most households have options to change behavior and reduce their energy consumption, some margins may be constrained by housing type, climate conditions, family size, landlord-tenant relationships, and other factors. These constraints may need to be taken into account in assessing equity concerns (e.g., "responsibility" and "merit" in the prioritarian and Aristotelian senses).

In the next section, we propose a framework for considering horizontal equity effects in assessing the costs of a policy and explain its roots. We then show how this relates to the welfare function in Slesnick (1989), which uses changes in utility relative to a reference point, as well as an aggregate welfare function based on the value functions put forward by Tversky and Kahneman (1992).

2. OPERATIONALIZING HORIZONTAL EQUITY IN WELFARE THEORY

As previously discussed, operationalizing horizontal equity into a welfare function faces the challenge of incorporating the referential nature of equal sacrifice while retaining sensible notions regarding redistribution. In this section, we draw on work by Slesnick (1989) and Kahneman and Tversky (1979) to motivate a particular welfare measure that includes horizontal and vertical equity. To make concepts clear, we specify an initial distribution of incomes, $\{y_i^0\}$, for a group of N households. These households are affected by a policy that leads to a distribution of changes (consumption variation) given

2. In contrast, the threshold for "significant regulatory action" requiring cost-benefit analysis is \$100 million, or just \$1 per household (US Government, Executive order 12866, Regulatory planning and review (1993)).

by $\{\Delta y_i\}$. We thus focus on motivating a welfare measure for a specific, policy-induced change in net income:[3]

$$W_0 = \overline{\Delta y} - \gamma N^{-1}\sum_i |\Delta y_i - r_i| \tag{1}$$

as well as a slight variant:

$$W_1 = \overline{\Delta y} - \gamma\sqrt{N^{-1}\sum\nolimits_i \frac{\bar{y}}{y_i^0}(\Delta y_i - r_i)^2}. \tag{2}$$

In both cases, W is scaled to household, monetary terms in the ballpark of the average household net income change, $\overline{\Delta y} = N^{-1}\Sigma_i \Delta y_i$. Here, r_i is a reference point for household i, where r_i is constructed such that $N^{-1}\Sigma_i r_i = \overline{\Delta y}$. The measure W_0 depends on the average absolute deviations from r_i, and W_1 depends on the squared (weighted) deviations from r_i. The parameter γ is a weight ($1 \geq \gamma \geq 0$) placed on the second term. We will go through the origins of these welfare functions momentarily—importantly, what might generate r_i—but for a moment we highlight a few features.

First, we refer to the second term, after γ, as an "equity penalty" arising from deviations from fair burden (when we want to refer to the term including γ, we will refer to the "weighted equity penalty"). The first term ($\overline{\Delta y}$) measures nonequity costs or benefits and simply depends on average (or, multiplied by N, total) costs or benefits. This term is unaffected by how those costs or benefits are distributed. The second term measures the effect of deviations from a particular distribution of burden given by the r_i's. These r_i's are able to capture the idea of vertical equity or fairness—the burden that households in different situations should bear to achieve the fairest possible outcome. To the extent actual household costs match those defined by the r_i, the penalty is zero. To the extent household costs differ from r, in either vertical (across initially different households) or horizontal (among initially similar households) ways, the penalty is positive and subtracts from welfare.[4]

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3. The purpose of the measures is to facilitate an evaluation of net benefits from a single policy or a choice among policies. We intentionally refer to W as a "welfare measure for a specific, policy-induced change" without suggesting that the measure should be treated as changes in some welfare level that cumulates policy after policy. For example, we do not refer to our expressions as ΔW.

4. It is worth noting that this welfare measure is subject to the Kaplow criticism that enacting a policy and then removing it can both involve adverse equity penalties. Imagine a policy that matches fair burden but then adds some random transfers among similarly situated individuals. The adverse equity penalty that would arise from both implementing and reversing the policy could be viewed as friction.

Second, the penalty is weighted by a scaling factor, γ. This is a social choice about the importance of equity concerns and is unavoidable to fully operationalize the welfare metric. As we discuss below, it is natural to constrain γ. In particular, it might not be so large that making a single person better off, without harming any other, lowers welfare, at least from the status quo, leading to our constraint that $\gamma \leq 1$. That addresses one of Kaplow's criticisms, noted above, that HE alone implies a violation of the Pareto principle.

Third, and perhaps most usefully, notions of horizontal and vertical equity can be decomposed. For example, suppose we define the reference point r_i to be the average burden in one's own decile $\overline{\Delta y}_{d(i)}$ where $d(i)$ maps individuals into deciles. (We do this formally in our modeling application section.) The penalty now approximates HE only. That is, the deciles as a whole are not penalized for whatever burden they bear, on average. The only penalty is for variation within the decile—whether similar individuals are treated similarly or not.[5] The additional penalty associated with alternative definitions of r_i comes from vertical inequity.

The fourth and last feature, which we demonstrate in our application, is that our measures allow quick and easy calculation of this HE component of the penalty term based on decile summary statistics. We can construct the HE penalty in W_0 from the average absolute deviation of burden by decile. And the HE penalty in W_1 is approximated based on the standard deviation of burden by decile. That is, if we compute the average absolute deviation of Δy_i and the standard deviation of Δy_i for each decile, the HE penalties in W_0 and W_1 are the simple and (approximately) weighted quadratic average across deciles, respectively, of these two statistics. These penalty functions are two cases of a more general penalty function,

$$\left(N^{-1}\sum_i \left(\frac{u_i'}{\overline{u'}}\right)^{\rho} |\Delta y_i - r_i|^{1+\rho}\right)^{\frac{1}{1+\rho}},$$

where u is a utility function and $\rho \geq 0$ is an inequality aversion parameter, which we discuss below.

We now turn to the literature to understand the underlying justification for (1) and (2).

2.1. Slesnick

Slesnick (1989) provides the main motivation for our welfare measure. He uses a welfare function based on deviations in household utility u from an initial reference point. Here, we have simplified his model to match our notation, making utility u solely a

5. We could instead imagine a more complicated scheme that would define r_i in terms of a more localized mean of the Δy_i's, rather than grouping households into deciles. This would be a more precise HE-only measure.

function of income. Specifically, the change in utility for individual i is given by $\Delta u_i = u(y_i^0 + \Delta y_i) - u(y_i^0)$.

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

$$W_s = \overline{\Delta u} - \gamma\left(\sum a_i \left|\Delta u_i - \overline{\Delta u}\right|^{1+\rho}\right)^{\frac{1}{1+\rho}}, \tag{3}$$

where $\overline{\Delta u} = \Sigma_i a_i \Delta u_i$ and $\Sigma_i a_i = 1$.

We can already see that (3) is somewhat similar to (1) and (2) in functional form, with one term capturing the average utility effect and the second a penalty for unequal distribution. That is, 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. This equity penalty includes horizontal inequity, when individuals with similar incomes face different utility changes. But it also includes vertical inequity, when, collectively, those individuals at a given income level deviate from the income change implied by $\overline{\Delta u}$ at that income level.

Without defining the weights in (3), rearranging burdens to minimize deviations in utility changes may affect average utility. However, by weighting the individual deviations by the inverse of marginal utility, we can completely disentangle total burdens and burden sharing. Let a_i represent normalized Negishi weights,[6] so

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

When these weights are used—and assuming income changes are small relative to total income, so $\Delta u_i = u'(y_i^0)\Delta y_i$—the average utility change reduces to a rescaled average income change:

$$\overline{\Delta u} = \sum a_i \Delta u_i = \frac{\sum_i u'\left(y_i^0\right)^{-1}\Delta u_i}{\sum_i u'\left(y_i^0\right)^{-1}} = \frac{\sum_i u'\left(y_i^0\right)^{-1} u'\left(y_i^0\right)\Delta y_i}{\sum_i u'\left(y_i^0\right)^{-1}} = \overline{u'} \times \overline{\Delta y},$$

6. Negishi (1960) formalized an insight for evaluating policies that do not have a primary goal of manipulating the distribution of income. It involved weighting individual utilities by the inverse of the marginal utility of income. With this weighting, the summed social welfare function replicates the market distribution, and marginal movements of income among individuals do not affect welfare.

where, as before, $\overline{\Delta y} = N^{-1}\Sigma\Delta y_i$ is the simple average change in income and $\overline{u'} = (N^{-1}\Sigma_i u'(y_i^0)^{-1})^{-1}$ is the harmonic average of individual marginal utility. In this way, we see that the first term in (3), $\overline{\Delta u}$, depends only on the average income change, not on how the income changes are allocated. That is, we can reallocate dollar costs across households without affecting the first term (or the basis of fair burden in the second term). The penalty is then minimized and welfare maximized with a burden reallocation such that $\Delta u(y_i^0) = \overline{\Delta u}$ for all households. In terms of income, this implies a specific notion of fair burden given by

$$r_i = r\left(y_i^0\right) = \frac{\overline{\Delta u}}{u'\left(y_i^0\right)} = \frac{\overline{u'}\,\overline{\Delta y}}{u'\left(y_i^0\right)}. \tag{4}$$

As shown in the appendix, we can use these values of a_i in (3) and r_i in (4) to produce $\overline{u'}W_0$ and $\overline{u'}W_1$ in (1) and (2) through a bit of manipulation and parameter assumptions. Hence, Slesnick provides one basis for choosing our welfare measures.

How does this expression for fair burden, $(\overline{u'}/u_i')\overline{\Delta y}$, in (4) vary across households with different incomes? That depends on the shape of the utility function. Suppose we assume iso-elastic utility, where

$$u_i = u(y_i) = (1-\tau)^{-1}y_i^{1-\tau}, \tag{5}$$

so $u'(y_i) = y_i^{-\tau}$. Consider two households, rich (R) and poor (P), where $y_R^0 > y_P^0$. Given the above expression for r_i, we have $r(y_R^0)/r(y_P^0) = (u_R'/u_P')^{-1} = (y_R^0/y_P^0)^{\tau}$. When $\tau = 1$ (i.e., log utility), the welfare-maximizing burden allocation is an equal percentage of income for all households. When $\tau > 1$, the rich household should pay a higher disproportionate share of income than the poor household. That is, $r(y_R^0)/r(y_P^0) > y_R/y_P$. When $\tau < 1$, the rich household still pays more in absolute terms but less than a proportionate share of income relative to the poorest.

The Negishi weights have another important and related consequence for the Slesnick welfare function. Imagine that we are examining an outcome where $0 > \Delta u_i(y_i) - \overline{\Delta u} > \Delta u_j(y_j) - \overline{\Delta u}$. Both households are faring worse than the average burden, $\overline{\Delta u}$. But household j is bearing a more extreme adverse burden. Consider a small transfer of income to household i from 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

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

which is positive so long as $\rho > 0$, given the larger deviation in utility 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 ρ in the Slesnick function. The form $(\Sigma_i a_i|\Delta u_i - \overline{\Delta u}|^{1+\rho})^{1/(1+\rho)}$ is an example of a power mean. This simplifies to an arithmetic mean of when $\rho = 0$ and standard deviation when $\rho = 1$, our two formulations of interest. More generally, the expression converges to the maximum value of $|\Delta u_i - \overline{\Delta u}|$ as $\rho \rightarrow \infty$ (see Bullen 2003, chap. 3). In other words, ρ governs the degree of aversion to extremes of inequality in the Pigou-Dalton sense, versus a general aversion to differences, however small or large. Larger values of ρ will imply more concerns about extreme deviations, while $\rho = 0$ cares only about the average deviation.

The only remaining parameter is γ. A value of $\gamma \geq 0$ simply reflects the relative importance of equity, measured by the second term, and overall cost, measured by the first. If γ is zero, there is no concern for the distribution of costs. For large values of γ, we are increasingly willing to accept a higher overall cost to society to achieve a more equitable burden. Slesnick picks γ to be as large as possible while still satisfying the criterion that a Pareto-improving policy raises welfare regardless of the distribution. As we show in the appendix, this amounts to $\gamma = 1$ for W_0. We require $\gamma \leq 1$ to be consistent with the Pareto criterion but are otherwise agnostic.

2.2. Prospect Theory

The welfare measure W_0 in (1) can also be motivated by 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.[7]

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 $\alpha \approx \beta \approx 1$.[8] Furthermore, the gain or loss is assessed relative to an individual reference point, r_i, so x in the value function is given by $x = \Delta y_i - r_i$ where Δy_i is again the income change for household i. We write an aggregate welfare function, including individual reference points and loss aversion:

7. 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.

8. This assumption implies that marginal utility is locally flat, allowing for straightforward aggregation.

$$W_{PT} = N^{-1} \underbrace{\sum_{i=1}^{N} r_i}_{\substack{\text{reference}\\ \text{points}}} - (1+\lambda) \underbrace{\left(N^{-1} \sum_{i=1}^{i^*} |\Delta y_i - r_i| \right)}_{\text{aggregate losses}} + \underbrace{\left(N^{-1} \sum_{i=i^*+1}^{N} |\Delta y_i - r_i| \right)}_{\text{aggregate gains}} \tag{6}$$

$$\equiv \overline{\Delta y} - \lambda \left(N^{-1} \sum_{i=1}^{i^*} |r_i - \Delta y_i| \right),$$

where we have ordered individuals from greatest loss to greatest gain, i^* is the last individual suffering a loss (e.g., $\Delta y_i < r_i$ for $i \leq i^*$ and $\Delta y_i \geq r_i$ for $i > i^*$), and $\lambda > 0$ for loss aversion. In order to simplify to the second line of (6), suppose the reference point is some notion of a fair allocation of burden for a particular aggregate burden, $\sum \Delta y_i$, so $\Sigma r_i = \Sigma \Delta y_i$ as before. With that assumption, the sum of the absolute value of losses equals the sum of the absolute value of gains: that is, $\Sigma_{i=1}^{i^*}(r_i - \Delta y_i) = \Sigma_{i=i^*+1}^{N}(\Delta y_i - r_i)$. We can further rewrite expression (6) to show that a mean-preserving increase in the absolute deviations of outcomes reduces welfare:

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

$$= \overline{\Delta y} - \frac{\lambda}{2} \left(N^{-1} \sum_{i=1}^{N} |r_i - \Delta y_i| \right).$$

Replacing $\gamma = \lambda/2$, this is the same expression as W_0 in (1). Prospect theory leads to a more generic notion of fair burden, r_i, which is otherwise determined by equal utility change in the Slesnick formulation. On the other hand, the Slesnick framework allows the incorporation of a more general notion of inequality aversion (ρ) that is sensitive to more extreme deviations from the welfare-maximizing burden. This motivates the alternative W_1 in (2).

2.3. Discussion

Ultimately, using either the Slesnick or prospect theory approach requires assigning values to what are at best subjective parameters of the social welfare function. These subjective parameters include the degree of inequality aversion γ in (3) or loss aversion λ in (6), the notion of utility curvature τ in (5) or fair burden r_i in (6), and the aversion to extreme inequality ρ in (3).

One approach is to assume values for some parameters in order to provide relatively simple expressions, as we have done for ρ in (1) and (2) and partly for τ in (2). For others, such as fair burden r_i and inequality aversion γ, we leave them unspecified for the moment. We then return to discuss these parameters as we present numerical welfare results and compare policies.

A somewhat different approach is to recognize that the distribution of Δy_i by decile (both within and across) approximates what matters for welfare. We can then present this information graphically and use summary statistics for various policy alternatives. The end users apply their own judgment and values to draw conclusions, rather than trying to choose parameters.

We now turn to a policy application to highlight these approaches.

3. MODELING HOUSEHOLD OUTCOMES UNDER DIFFERENT ELECTRICITY SECTOR POLICIES

We wish to make concrete our observations about horizontal equity as applied to energy regulation. To that end, we consider a stylized example of alternative policies designed to achieve the same carbon emissions outcome in the electric power sector: cap and trade (CAT) and tradable performance standards (TPS). This choice of policies is a particularly relevant question for stakeholders. Both types of policies have been proposed for the electric power sector over the past decade (Waxman 2009; Bingaman 2012). The Clean Power Plan also provided states with options for both rate-based (i.e., TPS) and mass-based trading (i.e., CAT). China is currently implementing a tradable performance standard in the power sector, even as other countries have embraced cap and trade (Pizer and Zhang 2018).

To construct our example, we first present a simple analytic model to highlight different household outcomes under the two policies and to relate those outcomes to a small number of parameters. We then use data from the Consumer Expenditure Survey and other sources to quantify the household outcomes. Subsequently, we show how these effects look when viewed through the lens of the welfare functions developed in the previous section.

3.1. Simple Electricity Sector Model

Our economic framework for comparing policies is a partial equilibrium model of the power sector. On the demand side, we focus on the case of perfectly inelastic electricity demand by each household. It may seem strange to abstract from the notion of demand response, which eliminates any aggregate cost advantage of CAT (the Pigouvian policy) over TPS in our simple model. That is, the underlying point of the paper is that there is an equity-efficiency trade-off, and here we assume that there is no efficiency advantage of CAT.

However, a necessary condition for an equity-efficiency trade-off is that equity effects are large enough that TPS could be preferred. By focusing on the case of inelastic demand, we focus on just how large the equity concern might be. Most importantly, fixing electricity demand simplifies our exposition. Each household's loss of real income equals its individual increase in electricity costs minus its share of any allowance value rebated directly to households.

On the supply side, we assume constant-returns-to-scale technology with the unit cost determined by the carbon price. This allows us to capture the key features that concern us. On the one hand, we want to see an increase in the cost of electricity associated with a carbon price under either TPS or CAT. On the other hand, we want to capture different electricity price effects when the associated allowance value is either rebated in the electricity price under TPS or assigned to households under CAT. These are the salient features of the more complex models we aspire to emulate, such as Burtraw and Palmer (2008).

Formally, let p_z be the electricity price, and p_m be the allowance price. Let C_0 be unit production costs in the absence of regulation. Market-based regulation adds two components: unit abatement costs (UAC) and unit emissions payments (UEP). If TAC is total abatement costs, then $UAC = TAC/Z$, where Z is the (fixed) aggregate generation. Assuming cost minimization over a constant-returns-to-scale technology, marginal abatement costs (MAC) are equal to the price ($\partial TAC/\partial M = p_m$). That is, we treat pollution like any other input that has to be purchased at price p_m, and we assume other input prices are fixed.

Total emissions payments are $TEP = p_m M$, where M is total emissions after responding to the regulation. Similar to converting TAC to UAC, unit emissions payments are defined as $UEP = TEP/Z = p_m(M/Z)$. That is, UEP equal the emissions price multiplied by the average emissions intensity per unit of generation. Since even freely allocated allowances have an opportunity cost, this component of the unit cost increase occurs regardless of how permits are allocated, and whether they arise under TPS or CAT. We refer to the emissions payments interchangeably as emissions rents or allowance value.

We see these cost components in figure 1, where M_0 is the emissions level when $p_m = 0$. As the electricity sector begins to pay a positive price $p_m > 0$ for its emissions, M, producers will begin to reduce emissions by $M_0 - M$. This incurs an abatement cost, the area under the MAC schedule, highlighted by region TAC in the figure.

Electricity producers also face a cost p_m for emissions that occur, M, highlighted by region TEP. We have drawn the figure for total generation, so we must scale the increase in total production costs by $1/Z$, the fixed total electricity demand, to relate the TEP to the change in unit costs of electricity production.

Notably, for all but very deep reduction targets, the size of the emissions rents is much larger than the total abatement costs ($TEP \gg TAC$). Thus, market-based policies create the potential for large redistributions, based on the allocation of these rents.

With CAT, the increase in electricity prices due to the regulation equals the sum of the UAC and UEC:

$$\Delta p_z^{\mathrm{CAT}} = UAC + UEP,$$

where the superscript CAT reflects the outcome under cap and trade. Allowance values are allocated in lump-sum fashion, so their distribution does not affect behavior or

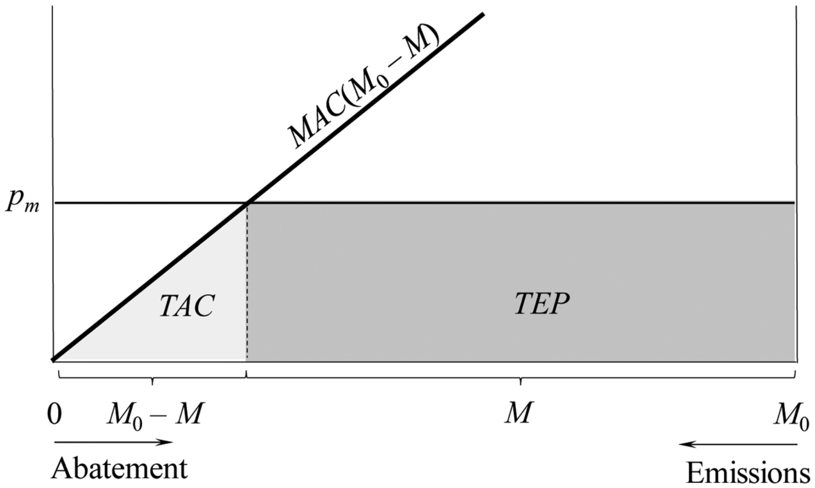


Figure 1. Comparing emissions rents, *TEP*, with compliance costs, *TAC*

electricity prices. Let us assume that the total allowance value *TEP* is rebated to each household *i* based on an assigned share s_i. That is, each household receives $s_i TEP$.

A TPS sets a performance rate *R* (expressed in pollution/unit of electricity). Each unit of generation is allocated allowances equal to this benchmark, *R*, and through trading an equilibrium is reached where the overall average emissions intensity equals the performance rate, or $M/Z = R$. Fixing total emissions to be the same under both policies, emissions prices and total emissions payments are as before (p_m and *TEP*). However, under TPS this allowance value is rebated as a subsidy to electricity production. At the unit level, this subsidy equals $p_m M/Z = p_m R = UEP$. This subsidy is passed on to consumers and serves to mitigate the electricity price increase:

$$\begin{aligned} \Delta p_z^{\mathrm{TPS}} &= UAC + UEP - p_m R \\ &= UAC. \end{aligned}$$

Here, the superscript TPS reflects the outcome under the tradable performance standard. That is, the unit cost increase is driven only by the abatement cost, not the allowance rent.

With this supply model, we can now turn to household outcomes. With households $i \in \{1, \ldots, N\}$, let Z_i represent household *i*'s fixed electricity consumption such that $Z = \Sigma_i Z_i$. As noted above, fixing this consumption implies that a household's loss of real income equals the increased cost of electricity minus any share of the allowance allocation. Under TPS this is given by $\Delta y_i^{\mathrm{TPS}} = -UAC \cdot Z_i$. Under a CAT, the real income change is given by $\Delta y_i^{\mathrm{CAT}} = -(UAC + UEP)Z_i + s_i \cdot TEP$;

that is, the added cost of buying the fixed electricity demand Z_i subtracted from the household's share of allowance value.

The difference between the policy outcomes for household *i* thus depends on whether the value of the household's share of the allowance revenues exceeds its share of electricity consumption: $\Delta y_i^{\text{CAT}} - \Delta y_i^{\text{TPS}} = (s_i \cdot TEP - Z_i \cdot UEP) = (s_i - Z_i/Z)TEP$. On net, both shares sum to one, so $\Sigma_i(s_i - Z_i/Z) = 0$ and aggregate costs for both polices are given by $N\overline{\Delta y} = \Sigma_i \Delta y_i = -TAC$.

At this point, for expositional purposes, we fix $s_i = 1/N$; that is, equal rebates per household. This cap-and-dividend approach is consistently suggested in various carbon pricing schemes (Inglis 2009; Larson 2015; Baker et al. 2017; Blumenauer 2017). Nonetheless, we return to this assumption at the very end of our analysis.

Table 1 summarizes the household outcomes for each policy and how they relate to summary cost parameters and data, with $\bar{Z} = Z/N$ as mean electricity consumption. Based on our model and assumptions, the TPS distributes the abatement costs according to electricity consumption shares, and the CAT policy adds a net emissions rent that is positive for households with below-average electricity consumption. These are the major differences that we want to capture. We now turn to the data that will allow us to quantify our earlier analytic results. In particular, we need to approximate the distribution of Z_i/Z, which equals the household share of total electricity expenditures in the population, and to choose the cost parameters TAC and TEP.

3.2. Household Data and Mitigation Cost

To provide a basis for likely variation in consumption of electricity and other demographics necessary for the calculations in table 1 and further discussion, 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: 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

Table 1. Hypothetical Policies for Numerical Analysis

	Effect on Household *i*
Tradable performance standard (TPS)	$\Delta y_i^{TPS} = -(TAC/N)(Z_i/\bar{Z})$
Cap and trade (CAT)	
with per household rebate	$\Delta y_i^{CAT} = -(TAC/N)(Z_i/\bar{Z}) + (TEP/N)(1 - Z_i/\bar{Z})$
Difference (CAT minus TPS)	$\Delta y_i^{CAT} - \Delta y_i^{TPS} = (TEP/N)(1 - Z_i/\bar{Z})$

Note. *TAC* is total abatement cost, *TEP* is total emissions payment, Z_i is household *i*'s electricity expenditure, $\bar{Z}$ is average electricity expenditure, and *N* is the total number of households.

Table 2. Summary Statistics for Numerical Exercise

	Observations	Mean	SD	Min	Max
Electricity (\$, C_0Z_i)	1,086	1,037	844	0	5,907
Log(electricity)	1,036	6.72	.764	3.64	8.68
Expenditures (\$, y_i^0)	1,086	35,936	32,518	1,902	330,237
Log(expenditures)	1,086	10.2	.821	7.55	12.71
Electricity share (%, C_0Z_i/y_i^0)	1,086	3.97	3.59	0	28.1

year (1,086). That is, we first match household respondents on their household identifier for each quarter of 2014 and keep only those households observed for all four quarters. We sum reported expenditures on electricity over these four quarters, as well as total expenditures.[9] Table 2 summarizes the data. We also indicate the notation we have been using that corresponds to each viable.

From table 1, we also need to specify the mitigation costs and rents, TAC and TEP. Based on recent analysis (EIA 2009), a reasonable assumption is that cap-and-trade regulation of carbon dioxide might raise electricity prices on the order of 10%. Based on other analysis (Burtraw and Palmer 2008), a reasonable assumption is that the actual cost (without the allowance revenue) is perhaps 10% of that (i.e., a 1% increase in electricity prices). Thus we choose $TAC = 0.01$ times the electricity expenditure in the sample and $TEP = 0.09$ times total electricity expenditure. Given the summary statistics, where the mean electricity expenditure ($C_0\bar{Z}$) was roughly \$1,000 per household, we have $TAC/N = \$10$ and $TEP/N = \$93$. With these data and parameters in hand, we now turn to our results.

4. POLICY COMPARISON AND WELFARE MEASURES

We plug the CEX data on Z_i and parameters TAC/N and TEP/N, all just discussed, into the expressions in table 1 for income effects by household. This yields distributions for Δy_i^{CAT} and Δy_i^{TPS} across households. Figure 2 presents these distributions graphically by decile using box-and-whisker plots where CAT is dark gray and TPS is light gray and deciles are arranged from poorest decile at the bottom to richest at the top. Two observations stand out. First, although the TPS outcomes are all negative (consistent with table 1), the CAT outcomes tend to be positive for poorer households. Because poorer households have smaller electricity expenditures, the per capita rebate under CAT leads to these positive welfare effects for the majority of households in the lower half of the income distribution. Second, the range of outcomes is much larger

9. Total expenditures (TOTEXPPQ) include all outlays by households for goods and services as well as contributions to pensions.

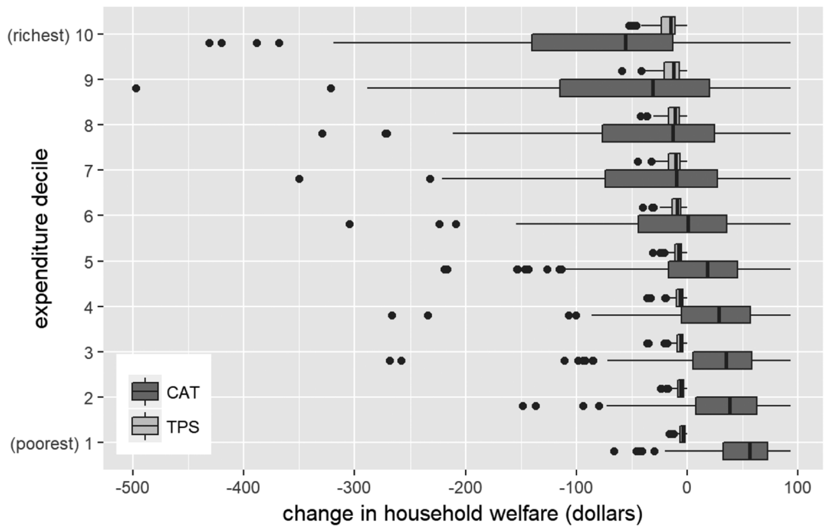


Figure 2. Comparison of cap and trade (CAT) and tradable performance standard (TPS), in dollars. *Note:* See table 1. $TAC/N = \$10$, $TEP/N = \$93$, and the distribution of $Z_i/\bar{Z}$ is as described in table 2. Boxes indicate interquartile range (IQR, 25th to 75th percentile). Vertical lines in the middle of the boxes indicate median. Horizontal lines, or whiskers, show the range of values outside the IQR, up to 1.5× the IQR. Dots indicate each individual value beyond the whiskers. For normally distributed data, such dots should have a frequency of ~1%.

within each decile under CAT than under TPS. For example, some households in even the poorest decile see negative effects under CAT. Among the poorest four deciles, roughly one-quarter remain worse off.

Note 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 (because the spread is unrelated to income). Later, we return to the idea of alternative ways to define the rebate, but arguably none of these alternatives would fundamentally change the distinction that CAT creates more within-decile variability than TPS.

This observation reflects one of the salient practical points of this paper. Although CAT policies can generally achieve any desired cost distribution across income groups, including positive outcomes, on average for the poorest, they cannot avoid significant variation. The range of outcomes is inherently much larger under CAT than under TPS because the rents *TEP* tend to be much larger than the mitigation costs *TAC*, and because there is significant within-income-group variation in household electricity use. Once rents enter electricity prices, this large, within-income-group variation will be difficult to ameliorate.

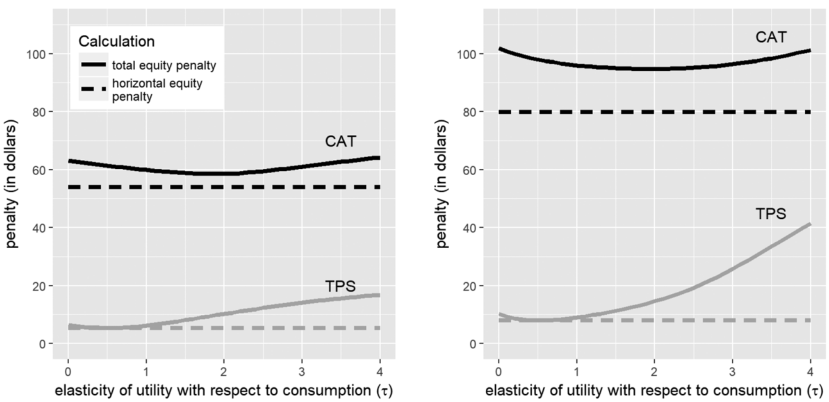
4.1. Measuring Welfare

How might this variability translate into welfare considerations? We now turn to our operational welfare measures, focusing mainly on the equity penalty term (recalling that the first welfare term equals $TAC/N = -\$10$ for both policies). The equity penalty arises from the failure of the actual distribution of household burden Δy_i to match the notion of fair burden r_i.

Based on the welfare measures in (1) and (2), we first calculate a "total equity penalty." We focus on Slesnick's definition (4) of fair burden $r_i = (\overline{u'}/u'_i)\overline{\Delta y}$. Using $u'(y_i) = y_i^{-\tau}$ as in (5) leads to $r_i = (y_i^0/\bar{y})^{\tau}\overline{\Delta y}$. As noted above, fair burden will rise as a share of income at higher income levels when $\tau > 1$ (and the reverse when $\tau < 1$).

We noted that one of the useful features of our welfare definitions (1) and (2) is that they allow a decomposition into horizontal and vertical equity effects. In addition to the total equity penalty, we also compute the "HE penalty" that arises when we substitute a reference point equal to the average burden in each household's income decile $r_i = \overline{\Delta y}_{d(i)}$, where $d(i)$ identifies that decile (e.g., d maps individuals $\{1, \ldots, N\}$ into deciles $\{1, \ldots, 10\}$).

Figure 3 graphs how the equity penalty varies with fair burden as defined by τ. The solid lines in the figure show the total equity penalty and dashed lines show the HE penalty. Values of both penalties appear along the vertical axis for CAT (black) and TPS (gray) policies, with values of τ indicated along the horizontal axis. The left panel shows W_0 and the right panel W_1. Note that the HE penalty does not vary with τ, having replaced the expression of r_i that depends on τ.



Equity Penalty $N^{-1}\sum|\Delta y_i - r_i|$ in W_0 in (1) Equity penalty $\sqrt{N^{-1}\sum_i(\bar{y}/y_i^0)(\Delta y_i - r_i)^2}$ in W_1 in (2)

Figure 3. Effect of varying power utility parameter τ on equity penalty. *Note:* For the solid line (total equity penalty), $r_i = (y_i^0/\bar{y})^{\tau}\overline{\Delta y}$. That is, fair burden is determined by equal changes in iso-elastic utility. For the dashed line (horizontal equity), $r_i = \overline{\Delta y}_{d(i)}$.

We make three observations. First, the penalties are uniformly larger for W_1 (right panel) than W_0 (left panel). As noted earlier, these two welfare measures can be derived as specific cases ($\rho = 0$ and $\rho = 1$) of the Slesnick welfare function (3). The parameter ρ determines the extent to which the penalty tends to the average absolute deviation versus the more extreme absolute deviations, with higher values of ρ putting more weight on more extreme values. Thus, it should not be surprising that, by assuming a larger ρ, W_1 yields larger equity penalties.

Second, the total equity penalty varies with τ, reaching a minimum in both the left and right panels at $\tau \sim 0.5$ for the TPS and $\tau \sim 2$ for the CAT. This reflects the idea that there is a value of τ where the fair burden over initial income levels, determined by τ, most closely matches each policy's actual distribution of average outcomes. At that value of τ, the penalty is minimized.

Finally, the CAT penalty is much higher than the TPS penalty. The welfare difference, ~\$50 per household for W_0 and ~\$80 for W_1, is large compared with the average cost (ignoring equity) of \$10 given by TAC/N. This difference is clearly driven by the HE component, as the dashed lines account for most of the difference between CAT and TPS.

This is the other major practical point of this paper. The variation of policy effects within income groups can be large under Pigouvian pricing. That variation translates into larger, negative horizontal equity consequences for Pigouvian versus non-Pigouvian policies. Depending on the weight given to these effects—e.g., the parameter γ in (1) and (2)—it appears large enough to overwhelm some differences in efficiency (e.g., differences in $\overline{\Delta y}$).

Despite its usefulness, missing from figure 3 is an understanding of how different deciles contribute to the equity penalty. Is the penalty, particularly the horizontal component, more sensitive to variation in the rich or poor? We answer that question in table 3. We present the same information as in figure 3 broken down by decile, for a single value of $\tau = 1$ (log utility). That is, eight columns (5–8 and 11–14) in table 3 take the values reported by the eight lines in figure 3 for $\tau = 1$, reproduce them in the last row, and then break them down by income decile in the remainder of the table.

The breakdown by deciles shows that poorer deciles contribute more to the equity penalty under W_1 than under W_0. Looking at either policy, and either the total equity or HE penalty, we see that the penalties uniformly decline moving from W_0 to W_1 for the richest decile but increase for the poorest. For example, horizontal equity for CAT declines from \$83 to \$59 for the richest decile and increases from \$27 to \$84 for the poorest. This may seem counterintuitive. The range of dollar values is actually largest for the richest decile in figure 2. Indeed, looking at the standard deviation of burden by decile, reported in columns 4 and 10, we see the largest values for the richest deciles. As discussed previously, the equity penalty in W_1 is generally larger than the penalty in W_0 because it puts more weight on extreme deviations, and the richest decile has the largest deviations.

Table 3. Summary by Decile of Total and Horizontal Equity Penalties ($) from Cap and Trade (CAT) versus Tradable Performance Standard (TPS), using W_0 and W_1

			CAT						TPS					
					Penalty*						Penalty*			
Income Decile	Avg. Income $\overline{y^0_{d(i)}}$ (1)	Fair Burden Defined by Log Utility (2)	Avg. Burden $\overline{\Delta y^{CAT}_{d(i)}}$ (3)	SD (4)	Total Equity (W_0) (5)	*HE* (W_0) (6)	Total Equity (W_1) (7)	*HE* (W_1) (8)	Avg. Burden $\overline{\Delta y^{TPS}_{d(i)}}$ (9)	SD (10)	Total Equity (W_0) (11)	*HE* (W_0) (12)	Total Equity (W_1) (13)	*HE* (W_1) (14)
10	108,100	−31.2	−84.5	107.2	84.5	83.5	65.6	59.3	−17.8	10.7	15.4	8.4	10.3	5.9
9	60,900	−17.6	−59.4	102.0	78.9	80.6	84.3	78.5	−15.3	10.2	8.6	8.1	8.1	7.9
8	46,100	−13.3	−33.5	79.3	61.8	62.4	71.7	69.5	−12.7	7.9	6.3	6.2	7.0	7.0
7	36,600	−10.6	−32.7	82.0	62.5	64.2	84.3	81.3	−12.6	8.2	6.3	6.4	8.4	8.1
6	29,300	−8.5	−13.5	69.1	51.3	52.3	77.2	77.0	−10.7	6.9	5.1	5.2	8.1	7.7
5	23,500	−6.8	2.3	67.3	52.7	49.5	84.3	83.6	−9.1	6.7	4.7	5.0	8.8	8.4
4	19,100	−5.5	16.6	59.7	51.6	42.7	87.3	81.9	−7.7	6.0	4.3	4.3	8.7	8.2
3	15,300	−4.4	21.7	61.3	52.9	42.1	103.7	95.5	−7.2	6.1	4.2	4.2	10.4	9.6
2	11,300	−3.3	30.8	47.1	49.8	35.6	104.0	83.7	−6.3	4.7	3.9	3.6	9.9	8.4
1	6,400	−1.9	47.9	34.2	54.3	27.1	161.1	84.5	−4.5	3.4	3.2	2.7	10.2	8.5
Total	35,900	−10.4	−10.4	74.1	60.1	53.9	96.2	79.9	−10.4	7.4	6.2	5.4	9.1	8.0

* Penalties computed using penalty term in eqs. (1) for W_0 and (2) for W_1. Total equity (cols. 5, 7, 11, 13) define $r_i = (y_i^0/\bar{y})\overline{\Delta y}$ (summarized by decile in col. 4). Horizontal equity (*HE*, cols. 6, 8, 12, 14) define $r_i = \overline{\Delta y_{d(i)}}$ as given in cols. 3 (for CAT) and 9 (for TPS). SD (cols. 4, 10) is the standard deviation.

The explanation lies in the weight $(\bar{y}/y_i^0)$ appearing in (2). In our derivation of (2) from the Slesnick welfare function, we embed an assumption of log utility with our assumption of $\rho = 1$ (see appendix). This implies a concern about variation in changes as a share of incomes. This leads us to down-weight rich households (where shares have a larger denominator) and up-weight poorer ones (where shares have a smaller denominator) based on $\bar{y}/y_i^0$. Usefully, the difference between the standard deviation by decile reported in columns 4 and 10 versus the exact HE calculation in columns 9 and 14 is largely a factor of $(\bar{y}/\overline{y_{d(i)}})$.

4.2. A More General Approach to Horizontal Equity

We have discussed our results in terms of the welfare measures W_0 and W_1. However, stakeholders may understandably be hesitant to embrace the ethical judgments of economists embedded in W_0 and W_1. This includes the choice of ρ in (3) and τ in (5), as well as the general "black box" nature of the calculations.

Conveniently, all the information necessary to make welfare judgments is contained in figure 2 and columns 3–4, 6, 9–10, and 12 in table 3, which provide information about outcomes by decile, including the central tendency and measures of spread, for each policy. Stakeholders can decide for themselves how much to weight deviations within deciles (horizontal equity) as well as how to value the central tendency of each decile (vertical equity) versus some objective. They need not buy into our particular assumptions embedded in W_0 and W_1. At the same time, the information is arguably consistent with the use of a welfare approach.

We view this approach as similar to the use of Lorenz curves. Lorenz curves represent a simple summary of income inequality relevant for applying a particular welfare measure. However, stakeholders can use Lorenz curves to understand inequality within society, and to make policy choices among alternatives, without necessarily using the particular welfare measure or adopting its particular ranking of outcomes.

4.3. Could CAT Do Better with More Targeted Rebates?

In our stylized comparison of CAT and TPS, we have suggested that CAT can have a higher equity penalty when we consider horizontal inequality. This stems from the considerable variation in within-income-group electricity use and CAT's higher effect on the electricity price. Lurking in this result is an assumption that we cannot fix these unequal effects after the fact, with targeted rebates that address this heterogeneity.

But could we? To what extent might we improve income-based redistribution and move toward targeted, within-income-group rebates? We know that electricity expenditures vary with household size and location, among other observed variables. How well can we predict electricity expenditures, controlling for income?

We explore this question by taking data from the CEX and trying to predict logged electricity expenditures. More precisely, we take all the household characteristics in the

CEX interview survey, convert categorical variables to indicators, and replace missing geographic identifiers with zeros.[10] This results in a set of 133 variables. With this enhanced data set, we have 879 complete observations (of 1,036 original observations). We then use 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.[11] Most of these are geographic or family composition indicators. However, all these variables together predict about half of total variation in electricity use (R-squared of 0.56), leaving considerable residual variation.[12]

We present these results graphically in figure 4. As in figure 2, we use box-and-whisker plots to show the variability within expenditure deciles, but here the horizontal axis shows expenditure share rather than dollar expenditures. Dark gray boxes are the raw data and light gray boxes are the residual variation after using these 35 variables to predict electricity expenditures. Visually, considerable variation remains (incrementally, income alone explains 28% of the variation).

While suggestive, this is still not a complete picture. The government will have considerably more information about individuals. For example, it may have more finely tuned geographic identifiers.[13] Such data may allow more precise targeting of rebates. However, we suspect that considerable variation will remain in housing age, design, and other factors, unless one is willing to turn to historical electricity use. And at some point, an increasingly complex scheme may become impractical.

5. CONCLUSION

Our principal motivation has been to highlight that Pigouvian policies 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

10. 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 publicly available 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.

11. This includes 19 geographic identifiers (two regional indicators, nine state indicators, and eight PSU indicators), six income variables (log expenditures, two rank variables, INC_RANK and ERANKHM, and three income category indicators), four family size and age variables (family size, one indicator for all children >17 years, two family type indicators), and six variables describing the housing location (two population size indicators, a rural-urban indicator, and two indicators of housing tenure).

12. Total expenditures alone predict 28%. These other 35 variables roughly double the predictive power.

13. We observe state or primary sampling unit for 88% of our sample. Nonetheless, many states (e.g., California) have a wide range of climate zones.

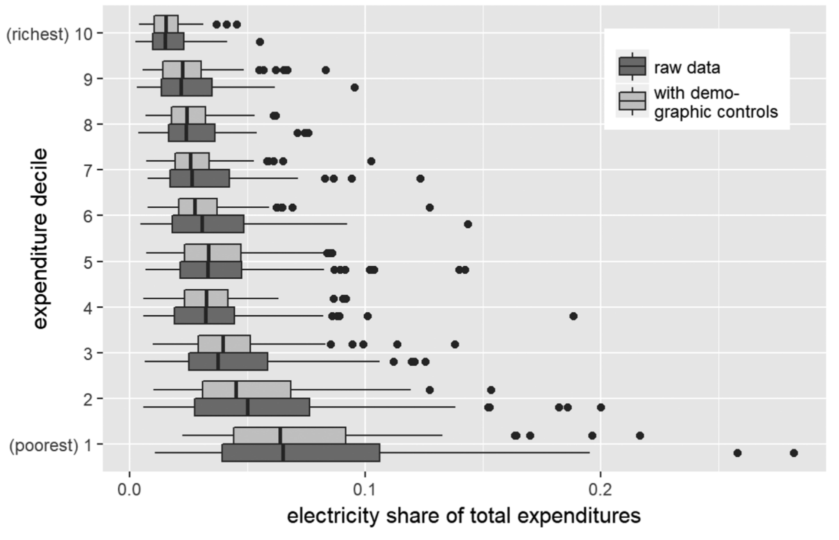


Figure 4. Box-and-whisker plots of electricity share by decile, highlighting the predictability of electricity expenditures using household income and other covariates (dark gray is actual data; light gray uses machine-learning algorithm to choose covariate controls). *Note:* Boxes indicate interquartile range (IQR, 25th to 75th percentile). Vertical lines in the middle of the boxes indicate median. Horizontal lines, or whiskers, show the range of values outside the IQR, up to 1.5× the IQR. Dots indicate each individual value beyond the whiskers. For normally distributed data, such dots should have a frequency of ∼1%.

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 given any level 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, treating those with similar income (and other characteristics) similarly, without an implicit welfare reward for redistribution from rich to poor. Generally, we would expect a regulation to entail a nonnegative burden for all households. As fair burden focuses on income changes, the approach does place special emphasis on the preregulation distribution of income as the primary basis for assigning burden. We have shown how to operationalize this approach by positing welfare measures based on Slesnick (1989) and prospect theory (Kahneman and Tversky

1979). Both theories lead to a penalty based on how household income changes deviate from fair burden or another reference point, incorporating both horizontal and vertical equity.

We made these ideas concrete through the stylized comparison of two policy options that have been proposed to address carbon dioxide emissions in the electricity sector—cap and trade with equal per household rebates (CAT) and tradable performance standards (TPS). CAT indeed leads to much wider variation in income changes across all income groups. Applying our welfare measure, we found that the associated CAT equity penalty is several times that of the TPS and potentially larger than efficiency advantages (about which we only speculate). A lingering question is whether more targeted rebates under CAT could ameliorate the otherwise large variation in income changes that underlies the penalty. Based on available data, the answer appears to be no.

Our welfare measure does not tell us how much to weight the equity penalty versus concerns about efficiency: that is a question of ethical and societal preferences. Such measures can also appear to be a "black box" to stakeholders, making them unappealing. For these reasons, we also emphasize practical and intuitive ways to present the relevant data that drive our welfare measures, including tables and figures describing the distribution of outcomes by income decile. This approach is analogous to the use of Lorenz curves to describe the income inequality associated with traditional welfare notions. By making the relevant outcomes easy to understand, stakeholders can draw their own conclusions directly, largely consistent with our welfare measures.

Given the oft-apparent disconnect between economists' promoting Pigouvian policies and policy makers' choosing non-Pigouvian alternatives, this paper raises an interesting possibility. Perhaps horizontal equity and distributional effects are something that policy makers have recognized for some time and that only economic analysis has tended to overlook.

APPENDIX

SIMPLIFYING SLESNICK TO PRODUCE OUR WELFARE MEASURES

With our choice of a_i to be Negishi weights, the result that $\overline{\Delta u} = \overline{u'}\,\overline{\Delta y}$, and the local approximation $\Delta u_i = u_i'\Delta y_i$, we can rewrite equation (3) as

$$W_s = \overline{u'}\,\overline{\Delta y} - \gamma\left(N^{-1}\sum_i\left(\frac{u_i'}{\overline{u'}}\right)^{-1}\left|u_i'\Delta y_i - \overline{u'}\,\overline{\Delta y}\right|^{1+\rho}\right)^{\frac{1}{1+\rho}}.$$

Rearranging slightly:

$$W_s = \overline{u'}\left(\overline{\Delta y} - \gamma\left(N^{-1}\sum_i\left(\frac{u_i'}{\overline{u'}}\right)^{\rho}\left|\Delta y_i - \left(u_i'\right)^{-1}\overline{u'}\,\overline{\Delta y}\right|^{1+\rho}\right)^{\frac{1}{1+\rho}}\right).$$

Defining $r_i = (u_i')^{-1}\overline{u'}\overline{\Delta y}$, for $\rho = 0$ we then have

$$W_s = \overline{u'}\left(\overline{\Delta y} - \gamma N^{-1}\sum_i |\Delta y_i - r_i|\right) = \overline{u'}W_0.$$

Further, assuming $u(y_i^0) = \ln(y_i^0)$ and $r_i = (u_i')^{-1}\overline{u'}\overline{\Delta y} = (y_i^0/\overline{y})\overline{\Delta y}$, for $\rho = 1$ we then have

$$W_s = \overline{u'}\left(\overline{\Delta y} - \gamma\sqrt{N^{-1}\sum_i \frac{\overline{y}}{y_i^0}(\Delta y_i - r_i)^2}\right) = \overline{u'}W_1.$$

We note that

$$\frac{dW_0}{d\Delta y_i} = \frac{1}{N} - \gamma\frac{1}{N}sign(\Delta y_i - r_i).$$

This will be nonnegative so long as $\gamma \leq 1$.

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