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ABSTRACT

Because electricity is a higher fraction of spending for those with low income, carbon taxes are believed to be regressive. Many argue, however, that their revenues can be used to offset the regressivity. We assess these claims by employing data on 322,000 families in the U.S. Treasury's Distribution Model to study vertical redistributions between rich and poor, as well as horizontal redistributions among families with common incomes but heterogeneous energy intensity of consumption (different home heating and cooling demands). Accounting for the statutory indexing of transfers, and measuring impacts on annual consumption as a proxy for permanent income, we find that the carbon tax burden is progressive, rising across deciles as a fraction of consumption. The rebate of revenue via transfers makes it even more progressive. In every decile, the standard deviation of the change in consumption as a fraction of consumption varies around 1% or 2% and is larger than the average burden (about 0.7%). When existing transfer programs are used to rebate revenue, the tax and rebate together increase that variation to more than 3% within each decile. The average family in the poorest decile gets a net tax cut of about 1% of consumption, but 44% of them get a net tax increase. Relative to no rebate, every type of rebate we consider increases this variation within most deciles.

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A market-based pricing policy such as a carbon tax or tradable permit program can reduce emissions at less cost than commonly-employed mandates like a renewable-fuel standard or energy efficiency standard (Goulder and Parry, 2008; Aldy *et al*. 2010). Despite their greater efficiency, however, carbon pricing has found little favor among U.S. policy makers for a variety of reasons. They may not trust the market to allocate resources efficiently, and they may place more value on objectives other than efficiency. Policymakers may also fear the distributional consequences of carbon pricing, particularly its oft-assumed regressivity. Indeed, carbon pricing likely raises the price of electricity and other carbon-intensive goods that constitute relatively high fractions of low-income family budgets (Metcalf 2009; Grainger and Kolstad 2010).

In response, economists point out that measured regressivity depends on how household income is defined and measured; on the consumer and producer shares of tax incidence; and on other features of policies. Moreover, they note that distributional objectives can be preserved by complimentary changes to government taxes and transfers. In the U.S., regressivity of a carbon tax can be neutralized by increasing progressivity of income taxes or use of the Earned Income Tax Credit (EITC). As Mankiw (2009) observed, "Economists in the Treasury Department are fully capable of designing a package of tax hikes and tax cuts that together internalize externalities and leave the overall distribution of the tax burden approximately unchanged."

While vertical redistributions between high- and low-income groups can perhaps be avoided by changes in tax and transfer programs, horizontal redistributions between families of comparable incomes may be more problematic. Because of heterogeneity of income sources and expenditures, any package of reforms is likely to create winners and losers within each income group. Retired workers' losses from a carbon tax are not offset by an expanded EITC or reduced income tax. Even if retirees could be compensated by expansion of social security benefits, poor families in harsh climates still bear a higher carbon tax burden than families of similar means residing in temperate areas with less energy use for home temperature control. Ineluctably, any attempt to target rebates to those who spend more on energy may implicitly encourage use of energy, diminishing efficiency of the carbon tax.

This paper assesses the capacity of existing transfer mechanisms to mitigate vertical and horizontal redistributions following the imposition of an energy tax. To do so, we account for the ways families vary—both within and across income groups—in their energy use, tax liability, and transfer program participation (see Blonz *et al*., 2011). We show the extent to which income-targeted transfers undercompensate some families and overcompensate others. In particular, we find that the average tax change in a decile conceals considerable heterogeneity within it. Because of large tax cuts for a minority of families, some reforms that produce average tax reductions across most deciles nevertheless yield small tax *increases* to majorities in each decile.

Economists have engaged in vociferous debate about the merits of horizontal equity as a policy criterion. Our intent is not to resolve this normative debate but only to report the extent of such redistributions. Policymakers may want to know if a reform introduces large gains and losses within income groups, as some may view these horizontal redistributions as capricious. And though disparate effects of a carbon tax may be viewed as consequences of household choices, additional disparity may arise from the use of the revenues to increase transfers.[1]

Poterba (1991) first demonstrated the expected disparate effects of energy taxes across households of similar means by documenting variation in their gasoline expenditures. Rausch, *et al.* (2011) have estimated variation in carbon tax burdens within income groups, but they did not look at effects of transfers intended to offset those burdens. To our knowledge, no scholarly research explores the extent to which both vertical and horizontal redistributions can be mitigated by reforms to tax and transfer programs.

One explanation for this omission is the absence of a publicly accessible dataset that provides the necessary information to evaluate the horizontal redistributions from income-targeted reforms. For a large sample of households, the U.S. Consumer Expenditure Survey (CEX) provides sufficient detail on purchases of various commodities whose prices are differentially affected by a carbon tax. However, it does not include detailed and verified information on income sources, taxes paid, and transfers received. Public-use tax returns are available with sufficient income and tax information, but they include scant information on transfers and expenditures.[2] Fortunately for our purposes, however, the U.S. Treasury in their Distribution Model (TDM) has undertaken extensive imputations to construct a dataset with the necessary heterogeneity across a large, representative sample of families of differing expenditures, sources of income, taxes paid, and transfers received.

[1] We focus on horizontal redistributions from differences in spending patterns and transfer receipts, but we note that a new policy can substantially affect returns to durable goods investments, like homes or automobiles, or it may affect employment or wages. Potential impacts of carbon pricing on the coal industry and Appalachian communities built around the coal industry have figured centrally in recent U.S. elections, as have impacts on relatively energy-intensive suburban communities (e.g., Glaeser and Kahn 2010, Stone 2015, Ummel 2016, Cass 2016).

[2] The National Bureau of Economic Research maintains a TAXSIM model that uses anonymized samples of Treasury tax returns. These data exclude very high earners and do not include the high-fidelity imputations of non-standard income that the Treasury Distribution Model incorporates. See http://www.nber.org/~taxsim/.

Our project uses the U.S. Treasury's merged file of 300,000 tax returns plus 22,000 non-filer "information returns" that captures those whose income is below the tax filing threshold.[3] This information permits the estimation of consumption for some of the poorest individuals. Analysis proceeds with an exact match of the social security number associated with each of these 322,000 returns to their social security benefits received and payroll taxes paid. Each return is also matched to a record of a similar family in the CEX, whose expenditure shares are attributed to the tax return family, with further imputations for transfer program participation and receipts (e.g. Temporary Assistance for Needy Families, TANF, and Supplemental Nutrition Assistance Program, SNAP). The next step is to calculate the effect of a carbon tax on the market price of each consumption good.[4] These price effects imply changes in the expenditures of each family, which are used to assess burden. The change in each family's burden is also calculated for each of three mechanisms for recycling carbon tax revenues. To the extent that revenue rebating mechanisms prevent extreme or capricious burdens, policymakers can take advantage of the efficiency afforded by market-based policies like taxes that minimize the cost of reducing carbon emissions without sacrificing distributional objectives.

We calculate and show the effects of (1) a carbon tax by itself and (2) a carbon tax with all net revenue returned by a per capita rebate.[5] We also show (3) a carbon tax with all revenue returned by a 5.9% increase in the EITC and all existing transfers, and (4) a carbon tax with half of revenue returned by a cut in the payroll tax and half returned through an increase in social security benefits. For all such reforms, we show effects across deciles and within each decile.

This analysis is limited in various ways. First, it ignores changes in factor prices and quantities consumed. Focus instead centers on household diversity in consumption of energy-intensive goods and in transfers received. Others study general equilibrium impacts on factor prices and consumption quantities, but usually with a limited number of household groups. The

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[3] Treasury's Distribution Model uses only non-dependent returns. The analysis below applies a weight to each return, where weights vary from 1 to 1,000. The resulting weighted dataset represents 172 million U.S. families.

[4] See similar methods in Metcalf (2009), Grainger and Kolstad (2010), or Mathur and Morris (2014).

[5] "The newly formed Climate Leadership Council — which includes James A. Baker, Henry Paulson, George P. Shultz, Marty Feldstein and Greg Mankiw — is proposing elimination of nearly all of the Obama administration's climate policies in exchange for a rising carbon tax that starts at $40 per ton, and is returned in the form of a quarterly check from the Social Security Administration to every American." We take that to mean per capita rebate. See https://www.washingtonpost.com/news/energy-environment/wp/2017/02/07/senior-republican-leaders-propose-replacing-obamas-climate-plans-with-a-carbon-tax/?postshare=621486571915785&tid=ss_tw&utm_term=.ecdad205b56a.

purpose of the present study is to shift from a limited number of household types to analysis of 322,000 families, which is accomplished only by limiting the analysis in other ways.

Second, we have one year's cross-section of data on consumption spending and transfer receipts, not a panel or other means to construct a long-run measure of well-being. Annual income is a poor measure of well-being, as low-income groups may include not only the perennially poor but also the young who will earn more later, the elderly who earned more earlier, and those with volatile income who are observed in a bad year. Instead, we rely upon annual consumption, to account for consumption smoothing (Poterba, 1989). Consumption is far from a perfect measure of permanent income, not least because of borrowing constraints and information problems, but it is better than annual income as a measure of family well-being.

Third, a broad carbon tax is analyzed at a single rate on all carbon emissions, not a tax on electricity or other sector's emissions that some may contend is more plausible in the U.S. Consideration of a broad tax has the advantage that it limits the sheer number of different calculations. In articulating conceptual issues regarding vertical and horizontal redistributions, this analysis suggests future research to understand both vertical and horizontal effects from a host of detailed proposals such as the U.S. Clean Power Plan.

Fourth, the merged dataset does not include information on each family's geographic location, housing and appliance vintages, or commuting distance to work—characteristics thought to affect exposure to carbon taxes. Thus, we cannot analyze compensation schemes tied to household characteristics other than income sources and transfer recipiency. Nevertheless, the final section of this paper discusses redistribution and efficiency implications of family-specific compensation schemes based on these family characteristics.

Notwithstanding these limitations, this analysis yields three key findings. First, despite the fact that electricity constitutes a high fraction of spending for poor families, our analysis finds that a U.S. carbon tax is progressive, not regressive as commonly assumed. In fact, its progressivity is a necessary consequence of the following four basic points: (1) once consumption is adopted as the measure of well-being, then a uniform consumption tax is not regressive but perfectly proportional; (2) as shown below, an aggregation of the various carbon-intensive goods is not clearly concentrated in high or low consumption deciles, which, with the first point, makes a carbon tax nearly proportional; (3) transfers in the U.S. are indexed to correct for increases in commodity prices that would accompany a carbon tax; and (4) transfers are a larger fraction of income for lower deciles.[6]

A second key finding is that the generally-ignored horizontal redistributions are much larger than the commonly-studied vertical redistributions. This result follows readily from the fact that the carbon tax is progressive but not very progressive. The average burden rises from only 0.45 percent of consumption in the poorest decile to 0.80 percent of consumption in the richest decile. In contrast, heterogeneity of consumption within any decile is larger. Intuitively, any decile may contain some families that live in moderate climates along the coasts and other families that are dependent upon electricity-powered air conditioning in the summer and fossil-fueled heat in the winter.

Third, any of the three mechanisms we study to rebate carbon tax revenues causes horizontal redistributions that are larger than those imposed by the carbon tax, itself. Family size, and, thus, per capita rebates vary within all deciles, but this variation is a larger fraction of consumption for those in low consumption deciles. Similarly, transfer receipts are a large fraction of income for the average family in poor deciles, but some families in those deciles receive small transfers or no transfers at all. Thus, a uniform increase in all existing transfers overcompensates some poor families for their carbon tax burden and provides no compensation to other poor families for their carbon tax burden.

The first section below reviews existing literature on the distributional impacts of carbon taxes and on the policy interest in vertical and horizontal equity. Section 2 describes the data and methods used to simulate carbon taxes and rebate programs. Section 3 discusses measures of income and reports summary statistics. Section 4 describes simulations, while section 5 shows distributional impacts. Section 6 considers policy implications of this analysis and alternative rebate schemes whose formal analysis is beyond the scope of this paper.

1. Overview of Distributional Effects of Carbon Policies and Rebates

Conventional wisdom holds that carbon pricing programs like tradable permits or carbon taxes burden the poor relative to the rich (e.g., Metcalf, 2009; Grainger and Kolstad, 2010; Rausch, *et al.* 2011; Williams *et al*. 2015). Consumer expenditure data from the U.S. and many European countries demonstrate that poor households devote greater shares of incomes to energy purchases

[6] Others discuss these points and show how they can help make the carbon tax progressive. See e.g. Fullerton *et al*. (2012) and Parry (2015), who also compares these effects for the U.S. and other countries. Our main contributions here are that we combine all four points within detailed calculations from the Treasury model for the U.S., and that we provide the first calculations of horizontal effects.

than do others (Pizer and Sexton 2016, Flues and Thomas 2015). Yet, recent literature shows that such distributional concerns may be misplaced or at least exaggerated. Measures of regressivity are diminished when evaluated according to lifetime income or permanent income, or a proxy such as annual expenditures. In contrast, annual incomes fluctuate with spells of unemployment, changes in health status and family conditions, other shocks, and well-known lifecycle effects in earnings and savings (Poterba 1989, Bull *et al.* 1994, Hasset *et al*. 2009, Sterner 2012). According to the permanent income hypothesis of Friedman (1957), the smoothing of household consumption over time implies that annual consumption is better than annual income as a proxy for permanent income. For this reason, carbon tax regressivity can be exaggerated when using annual income rather than annual total consumption to classify families from rich to poor.

The vertical redistributions that do attend the introduction of carbon taxes can be diminished by complimentary reforms of tax and transfer programs that utilize carbon tax revenues. Mathur and Morris (2014), Dinan (2012), and Metcalf (1999, 2009) consider how to offset regressivity using existing tax code and transfer programs or lump sum rebates. By refunding merely 11% of revenues, for example, the poorest quintile of households can be fully compensated—on average—for the added cost of a $15 per ton tax on carbon dioxide (CO_2) emissions (Mathur and Morris 2014). Metcalf (2009) develops a revenue-neutral tax reform package that raises $88 billion from a $15 tax per ton of CO_2 emissions and returns the revenue through an EITC of up to $560 per worker. However, such revenue recycling for the sake of equity comes at the cost of foregone economic efficiency of the tax. Efficiency would dictate that carbon tax revenues be used to reduce the most distorting taxes, which tend to be progressive.[7] Carbon tax regressivity can be exacerbated rather than ameliorated by efficient reductions in progressive taxes like those on personal income, corporate income, and capital income.

When the distributional impacts of many and various tax and expenditure programs are evaluated, attention is focused on vertical impacts with little attention to horizontal impacts. For carbon pricing, considerable variations in burdens are caused by household heterogeneity in income sources, transfer program recipiency, and energy demands. Pizer and Sexton (2016) observe that variation in energy consumption within income groups generally exceeds variation across income groups in the U.S., Mexico, and United Kingdom. In the U.S., some of the poorest

[7] See Bovenberg and de Mooij, 1994; Carbone, *et al*., 2013; Cramton and Kerr, 2002; Fullerton and Metcalf, 2001; Goulder, 1995, 2002; Bovenberg and Goulder, 2002; Goulder *et al*. 1999; Parry, 1995; Parry and Bento, 2000.

households devote nearly 20% of total spending to electricity, while other poor households incur no direct electricity expenses at all (i.e., when electricity is included in rent). Overall, variation is induced by differences in household size, home ownership status, climate, electricity generating infrastructure, home size and vintage, vehicle miles travelled, and energy efficiency of durable goods, among other characteristics. This household heterogeneity introduces carbon tax burden differences that cannot be fully overcome without direct efficiency implications.

While differences in energy use lead to disparity in carbon tax burdens among otherwise similar households, Williams *et al*. (2015) found in a general equilibrium setting that variation in carbon tax burdens depends on how carbon tax revenues are rebated. This heterogeneity from income sources such as transfers is potentially easier to remedy, because of income reporting requirements and opportunities to target refunds according to income sources. Nevertheless, this targeting can be complicated by variation within an income group's benefit eligibility, take-up rates, and actual receipts. Only 32% of families in our lowest decile receive the EITC benefits.[8] Alternatively, carbon tax burdens might be offset by use of programs like Medicare, SNAP, and the Special Supplemental Nutrition Program for Women, Infants and Children (WIC). However, recipients of these programs are a minority of families in all income groups. Only 19% of the poorest U.S. families receive SNAP benefits, while 16% receive social security income.[9]

High rates of payroll tax liability and of social security recipiency among most income groups suggest that a combination of payroll tax reductions and expanded social security benefits could offset carbon tax burdens for nearly all but the poorest families. But horizontal redistributions among the poorest families may prove particularly difficult to remedy. Among the poorest families, 27% neither incur payroll tax liabilities nor receive social security benefits. Thus, the design of a carbon tax that avoids horizontal redistributions—particularly among the lowest-income families—is not straightforward.

While policy interest in vertical equity follows directly from the concept of diminishing

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[8] On EITC participation, see Eissa and Hoynes (2011). Benefit recipiency rates here are based on our U.S. Treasury data. Only 19% of families in the lowest decile receive SNAP benefits, while 16% receive Supplemental Security Income. Incomplete take-up rates observed across transfer programs are attributed to welfare stigma, transaction costs, and imperfect information (Currie 2006). Others estimate that $6.7 million each year goes unclaimed by those eligible (Barghava and Dayanand 2015). Estimates of Unemployment Insurance take-up range from 53% to 71% (Anderson and Meyer 1997).

[9] SNAP and social security benefits are included in the Treasury's cash income measure. Recipients will therefore be ranked higher than otherwise similar non-recipients. In Treasury's model, 46% of families in the second-lowest income decile receive either SNAP or social security benefits, compared to 33% in the lowest income decile.

marginal utility of income within the utilitarian social welfare framework (e.g., Bentham, 1802), the theoretic foundation for horizontal equity is less straightforward and is subject to debate among economists. Sidgwick (1874) argued that horizontal equity can be the ultimate principle of distributive justice. And as Simons (1950) noted, "it is generally agreed that taxes should bear similarly upon all people in similar circumstances," which we might understand to mean people of similar means. The notion that equals should be treated equally by policy has intuitive appeal and popularity among economists (Atkinson and Stiglitz 1980, Stiglitz 1982).

Yet Stiglitz (1982) showed that horizontal equity does not derive from the social welfare or utilitarian criterion; it may even contravene conventional welfare maximization and countermand the Pareto principle. This critique is shared by Kaplow (2000). Pursuit of horizontal equity may require reduction of some individual welfares to achieve common outcomes, and it may give preference for common outcomes over those in which individual welfare levels are higher but heterogeneous. Kaplow (1989, 1992, 1995, 2000) argues that preference for the original or *ex ante* outcomes over post-tax outcomes is morally arbitrary. He also contends that horizontal equity is trivially satisfied whenever vertical equity is satisfied "because whatever reasons motivate a particular treatment of one individual will require the same treatment of another individual who is equal in all relevant respects" (Kaplow 1989, p. 143).

By Kaplow's definition of equals "in all relevant respects," a carbon tax would preserve horizontal equity by treating equally all households with identical incomes, income sources, and consumption. Nevertheless, it would impose heterogeneous burdens on households of similar means. It is these disparities that impelled Musgrave (1959) to contend that the normative underpinnings of horizontal equity and vertical equity are one and the same.

The primacy of horizontal equity as a normative rule, Musgrave (1990) asserted, is derived from distributive justice theories ranging from Lockean "entitlement" to Rawlsian "fairness." Indeed, the "benefit principle" of taxation would equate taxes among households of comparable incomes and common tastes, because of their common valuations of the marginal unit of a public good. Likewise, under an "ability to pay" principle, common taxation of individuals with equal incomes would also prevail. And horizontal equity also holds under the neo-utilitarian and Rawlsian approaches to distribution decisions where each person decides principles of justice "from behind the veil of ignorance," without knowing his or her own endowments. In some ways, the basis for vertical equity is *less* firmly rooted across distributive justice theories (Musgrave 1990), and far more contentious (Auerbach and Hassett 2002).

Stiglitz (1982) reconciled horizontal equity with welfare maximization by broadening the definition of social welfare. Auerbach and Hassett (2002) also give it independent normative content using a theory that society cares more about differential treatment among proximal individuals in the income distribution than it cares about inequality across the entire distribution. With different welfare weights applied to deviations in "local" income versus deviations in "global" income, horizontal equity becomes a distinct component of inequality aversion.

Here, we distinguish two concepts of horizontal equity. Most of the debate above is about the concern that *levels* of tax burdens may differ for families with the same income. A different possible concern is that *changes* in tax burdens might be viewed as arbitrary—and therefore unfair— windfall gains and losses to families with the same income. We do not try to resolve these philosophical questions. Instead, we aim only to show what *are* the vertical and horizontal redistributions caused by alternative carbon tax and rebate reform packages.

2. Treasury's Distribution Model

The Office of Tax Analysis of the U.S. Department of the Treasury has constructed a dataset and model that we refer to as Treasury's Distribution Model (TDM). We use it to estimate impacts of a U.S. carbon tax and of alternative rebate mechanisms. In this section, we describe the model in four main steps (summarized here, and described further below).[10] First, the TDM uses 300,000 individual income tax returns and 22,000 information returns for a total of 322,000 families (weighted to represent a population of 172 million families). Each family's annual consumption spending is calculated as cash income minus income taxes, payroll taxes, and an estimate of savings. Second, each tax family is matched to a similar family in the CEX data, and that CEX family's expenditure shares for 33 consumption categories are applied to the total expenditures of the tax family to calculate expenditures on each category of goods. Third, the direct and indirect impacts of a carbon tax on each of 389 commodity prices is estimated using a partial equilibrium, input-output model. And finally, these price changes are used to compute post-carbon-tax expenditures. [11] Expenditures change only because of a commodity price changes,

[10] See Cronin (forthcoming) for a complete description of Treasury's Distribution Model.

[11] Distributional effects could be measured by money-metric utility, or the trapezoid loss in consume surplus. Because our aim is to explore distributional consequences of a carbon tax rather than efficiency implications or deadweight loss, we focus on first-order effects rather than second-order effects of behavioral responses that may include households and firms substituting away from energy-intensive consumption and input-use. Accounting for such substitutions would be analytically costly, as it would require many more elasticity assumptions. Nonetheless, such behavioral responses can bear on the regressivity of carbon taxes, as in West and Williams (2004).

while quantities are assumed to be unchanged.[12]

Our use of individual tax returns mitigates measurement error in family consumption, and it affords reliable determinations of tax liability, both of which are important for our tax reform simulations. Still, the data are imperfect, and various categories of income and consumption must be imputed as is explained in this section. The accuracy of these imputations, however, is likely superior to other approaches because of the richness of Treasury data.

Each family's total consumption in 2017 is calculated for a stratified random sample of 300,000 individual non-dependent income tax returns drawn from among 143 million returns filed for 2010.[13] These returns are supplemented with tax records for 22,000 similarly sampled non-deceased non-filers using "information returns". These information returns include Forms W-2 filed by employers and various Forms 1099, including those filed by the Social Security Administration to report benefits. Tax families are generated from these individual information returns based on filing status in previous years, age, targets for the non-filing population from the Social Security Administration, and targets for non-filing family structure based on Census. Together, these income tax and information returns are used to generate tax records for a population of 334 million people, or 172 million families, 28 million of whom do not file an individual income tax return.[14] The base file is for 2010 but is extrapolated to 2017 conditional on expected population size, national income, inflation, employment, and interest rates.

By employing individual tax returns and information returns for non-filers, this approach benefits from reliable reporting of most income. However, because some income is untaxed and some is unreported, a full measure of family welfare requires imputation of some income

[12] Note two points here. First, each of the 389 commodity categories for which the price rises due to the carbon tax must be mapped into the 33 consumption categories for each family. Second, the assumption that quantities are fixed might not matter much for overall regressivity if actual demand elasticities are similar across deciles. If demand is more price-inelastic for poor families than for rich ones, however, then burdens can be more regressive than measured here (West and Williams, 2004).

[13] Our unit of analysis is the tax family. Each tax family includes the taxpayer, his or her spouse (if married), and any dependents living in the household or away at college. Tax families outnumber households, because some households include more than one tax family. An analysis based on households will rank two-family households higher in the income distribution than each single-family household, all else equal.

[14] The tax sample has two components: first is a random sample of social security number (SSN), and second is an oversample of high-income returns and returns with certain low-probability characteristics such as negative income or a high number of capital gains transactions. Oversampled strata receive lower weights. The highest-income returns have a weight of one (all are included in the sample). Treasury uses the same sample design to choose non-filers from information returns filed on individuals who do not file an income tax return. If an individual with one of the random SSN ending-digits receives a W2 or a 1099 but does not file an income tax return because they are below the filing threshold, then they are included in the sample. Weights are adjusted in the extrapolation to hit population and family structure targets from Social Security Administration data and Census data.

sources.[15] Imputed "cash income" includes such employer-provided fringe benefits as military service allowances, transportation and education benefits, as well as employer contributions to health and life insurance policies.[16] Medical Expenditure Survey data and administrative records of the Department of Health and Human Services are used to impute Medicare, Medicaid and workers' compensation health benefits. The Current Population Survey (CPS) is used to impute transfer benefits, including those from SNAP, WIC, TANF, and Low Income Home Energy Assistance Program (LIHEAP).[17] Savings and dis-savings are imputed from the Survey of Consumer Finances (SCF).[18]

For each of these simulated tax families, consumption is computed as cash income less tax payments and savings (or dissaving), where cash income includes wages and salaries, net income from a business or farm, taxable and tax-exempt interest, dividends, rental income, realized capital gains, cash or near-cash transfers from government, distributed retirement benefits, and employer fringe benefits. It is assumed that family consumption is equal to at least half of the federal poverty level corresponding to their family size. Families whose estimated consumption falls short of this threshold are assumed to finance this minimum consumption from unmeasured transfers or debt financing. This assumption has the effect of increasing the average consumption of the poorest 10% of families by almost 50%.

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[15] The assignment of the non-tax-based income items is subject to greater measurement error than the tax-based items but, to the extent possible, Treasury uses the tax data to make informed imputations. For example, military allowances are only allocated to taxpayers that are in the military. And, qualifying for welfare assistance in the imputations depends on having taxable income and demographic characteristics on a tax return that are consistent with each welfare program's requirements. See Cronin (forthcoming) for a complete description of the income imputations in the TDM.

[16] Some readers might like to see a measure of family economic income that includes accrued but unrealized income, evaded income unreported on the tax returns, and imputed net rent of owner-occupied housing. In earlier models, Treasury used a broader Haig-Simons type economic income measure called Family Economic Income (FEI) (Cronin, 1999). Accrued and unreported income, however, are difficult to attribute accurately across families, and the FEI concept was more difficult for the general users of distribution tables to understand. As a result, Treasury began using cash income to rank families. Family economic income may be larger, but the rankings of families by cash income are similar to rankings by some estimates of economic income.

[17] For each transfer program, the TDM uses CPS data and a logistic regression to estimate the probability that a family in the tax data would receive a particular transfer (e.g., SNAP). Regressors in the logistic equation include age of the primary taxpayer, filing status, number of children under 18, AGI, and interest income. Tax families are then sorted into cells based on filing status, annual AGI, and the presence of children. Within each cell, families are ranked by their probability of program participation, and the families with the highest likelihood of participation are selected as participants (where the total number of participants within a cell is targeted to the CPS in the initial imputation). Transfer levels are then randomly matched between the CPS cells and the tax data cells. All imputations are done at 2010 levels and then extrapolated to 2017 for the distribution model. Participation and levels are adjusted to match expected participation and budget outlays for each program.

[18] Forty savings rates are imputed that vary by marital status, age, and income.

In order to estimate carbon tax burdens across families, each family is matched to a record of the CEX that reports expenditures across 33 categories of goods, the prices of which change with the introduction of a carbon tax. The match is based on cells in the CEX defined by marital status, five age categories, five categories of family size, and 18 expenditure ranks (from lowest 5% to top 10%). These distinctions yield 900 combinations or cells to which CEX records belong – and to which tax families are assigned. Only CEX records from 2010-2012 that include four quarters of expenditures are employed, yielding 4,943 records that match to 704 of the CEX cells; no CEX records match any of the remaining 196 cells.[19] The median CEX cell includes four CEX records, though some contain as many as 99 CEX records. Each tax family is randomly assigned to a CEX expenditure record from its corresponding CEX cell. For tax families whose characteristics match to an empty CEX cell, expenditure records are selected from among those of the next lowest expenditure rank. This nearest neighbor match is employed in fewer than 1% of records. The tax family's total expenditures are then allocated among the 33 categories by assuming that the tax family has the same expenditure shares as the family in the matched CEX record. To these imputed expenditures are added consumption from employer fringe benefits that cover costs not reported in the CEX, including transportation and education benefits, as well as employer-paid child care and insurance benefits. Addition of this fringe consumption most substantially increases consumption in the health category, which rises from 8% of total out-of-pocket expenditures to 17% of total consumption.

Treasury's model is based on tax data, and most income items have third-party verification. This verification reduces income measurement error that may arise from self-reporting bias in survey data. It is also not subject to measurement errors from top coding, or small sample size like some publicly available data.

The carbon tax burden for each family is readily calculated, given its consumption amount and the calculated price changes for each of the 33 consumption goods. To obtain the partial equilibrium price changes induced by a $25 per ton carbon tax, Treasury employs an input-output model to compute the price change for each consumption good according to the price changes in the intermediate inputs for each consumption category.[20] The carbon tax

[19] Budget shares may be different today than they were during 2010-2012, the period over which we measure family budget shares. For example, budget shares may change because of changes in relative prices. The current version of the model that we employ does not incorporate more recent budget share data.

[20] See, e.g., Fullerton (1996), Metcalf (1999, 2009), Hassett *et al*. (2009), and Mathur and Morris (2014).

directly impacts the price of fuels, according to their carbon intensities. Using estimates of carbon intensity from the U.S. Energy Information Administration and the Environmental Protection Agency, we calculate that a $25 tax per metric ton of carbon would increase the price of coal by 133%. Petroleum prices rise by 27%, and natural gas prices by 44% (see Table 1). These price increases are greater than the price increases estimated in Metcalf (2007) and used by Hassett *et al*. (2009) for a $15 tax per metric ton of carbon. Metcalf (2007) estimates that a $15 tax per metric ton of carbon would increase the price of coal by 91%, the price of petroleum by 13% and the price of natural gas by 6% relative to average prices in 2005. The much higher 44% price increase for natural gas in our analysis is the result of both a higher carbon tax rate and a much lower price for natural gas in our more recent year (expected to continue into 2017).[21]

Because these fuels are intermediate inputs in the production of most other consumption goods, these estimated fuel price increases induce price increases in other products according to their fuel intensities. To determine these indirect price changes, the Treasury model employs the U.S. Bureau of Economic Analysis's 2007 benchmark input-output tables. These tables, the most recent available, show how much of each commodity is produced by each of 389 industries and how much of each commodity is consumed in production by each industry. The fuel price increases are applied at the extraction level for oil and gas and at the mining level for coal. When the price increases are initially applied, firms in the 389 industries pass all of their costs along to the purchaser.[22] This assumption results in commodity price increases across the 389 industries, which leads to another round of price hikes.[23] Treasury iterates on this process (using the 389 industry input-output tables) until the price changes being observed are sufficiently small. At this point, to obtain the final purchaser price of the commodity, they apply margins for

[21] The Henry Hub natural gas spot price was $13.05 per million Btu in December 2005 but is projected to be only $2.95 in 2017.

[22] The pass-forward assumption is standard in the literature, though some research has demonstrated that perceived regressivity varies according to whether policy costs are passed forward to consumers or passed backward to factors of production (e.g., Hassett, *et al.* 2009, or Parry *et al*. 2015). Also, note that much of the power sector is still subject to price regulation, and the marginal fuels determining prices can be different from the baseload fuels. In the short run, depending on its phase-in, a new carbon tax may displace some workers, such as coal miners, and it may be capitalized into certain stock prices or land prices. Thus, during the transition, the carbon tax is not all passed forward to consumers but instead borne by particular human or physical capital owners. While substantial short run burdens are imposed on some families, our calculations here can only consider the long run steady state.

[23] In fact, Treasury splits oil and gas in the Benchmark I-O table, so they are actually using 390 industries.

transportation, retail, and wholesale trade.[24] The price changes for the 389 commodities are then mapped to changes in the 33 consumption goods defined in the CEX and imputed to the TDM.[25] Our calculated price changes from the carbon tax are reported in the last column of Table 2 (while earlier columns show the corresponding price changes calculated in previous studies). Most indirect price increases are less than 1%. The greatest indirect price changes for non-energy outputs are for mass transit (4.6%) and air transportation (5.5%). The table uses bold for the four carbon-intensive consumer goods with the largest percentage price increases: electricity (9.0%), natural gas (14.8%), home heating oil (14.5%), and gasoline (14.8%).

3. Measures of Income and Summary Statistics

In order to measure distributional effects across income groups, we need to choose a measure of "income" to rank families and divide them into deciles. The most common measure employed in many studies over past decades is a measure of annual income (preferably a more inclusive measure than taxable income). Yet annual income is not a good measure of who is doing well or poorly. Each group is an aggregation of very dissimilar individuals, many of whom are only temporarily in that annual income decile. Generally, annual income is affected by stage of the lifecycle, changes to unemployment, health, and family conditions. If those with positive income shocks save more of annual income than those with negative income shocks, then classification by annual income exaggerates the regressivity of energy taxes that raise commodity prices (Poterba, 1989; Bull, *et al*., 1994, Sterner, 2012).

In contrast, under the Permanent Income Hypothesis (Friedman, 1957), annual consumption is less sensitive to shocks and exhibits less severe life-cycle patterns.[26] Therefore a more meaningful measure of well-being might be a measure such as permanent income or

[24] These margins are provided by BEA as part of the input-output tables, and the prices for these margins also increase with the imposition of the carbon tax. For example, a $100 spent on a particular good at producer prices might translate to $120 for a final purchaser when retail and transportation costs are added. The price increases for that good and the margins are separately estimated and, then, aggregated to obtain the final purchasing price.

[25] The mapping from the BEA's Personal Consumption Expenditure (PCE) to the CEX is based on a concordance between the PCE and CEX categories as provided by the Bureau of Labor Statistics (BLS). The latest available BLS concordance uses the PCE 2002 benchmark, but Treasury updated its mapping to the 2007 benchmark and had to make adjustments to map consumption categories not included in the CEX (health consumption in particular).

[26] Bull, *et al*. (1994) observe in U.S. CEX data that consumption closely follows income, exhibiting a "marked hump-shaped pattern" over lifetimes, rather than remaining relatively flat as posited by the Permanent Income Hypothesis. Therefore, they account for energy tax incidence on lifetime consumption by adjusting current household consumption to reflect the typical lifetime consumption profiles for similar households.

lifetime income. Yet, such measures can be very difficult to estimate.[27]

Here, we have only one year of data for each tax family, but even these data can provide a reasonable proxy for lifetime income. Suppose that each household does consider its expected future annual incomes, that it employs a present-value budget constraint to choose current annual consumption, and that annual consumption exhibits diminishing marginal utility. Under these conditions, Poterba (1991) points out that households will choose a smooth consumption pattern that reflects permanent income. As a consequence, annual consumption is a good proxy for permanent income, or at least it is better than annual income as a proxy for permanent income.[28]

Therefore, in our analysis of distributional impacts, we choose to stratify families according to total annual consumption rather than annual income. In fact, except in Table 5, we do not classify families by annual income at all.

For families classified into annual consumption deciles, the TDM's distribution of income and consumption at 2017 levels is reported in Table 3. In total, consumption is equal to 70% of income. The ten percent of families with the highest annual consumption accrue 44.3% of total cash income and consume 36% of all goods and services. The poorest 10% of families by that measure have only 1% of income and consume 1.8% of all goods and services. Cash incomes are more skewed toward the rich than are consumption levels, because high-income families bear greater tax burdens and save more than low-income families.

Table 4 reports mean consumption shares for each decile of total consumption and each consumption category. The greatest consumption shares for all deciles are in food, housing, and health. Consumption shares for health decline markedly across deciles, from 32% for the poorest ten percent of families to 10% for the richest families. Total food consumption shares vary less, from 14% for the poorest families to 10% for the richest families. Interestingly, mass transit constitutes less than 1% of expenditures across deciles. Expenditures on the most energy-intensive goods comprise in total less than 11% of overall consumption across deciles (including the four goods in bold that had the largest price increases in Table 2, namely electricity, natural

[27] Fullerton and Rogers (1994) and other studies calculate tax incidence using overlapping-generations models of households classified by an estimate of lifetime income – the present value of all wage income plus inheritances. The measure can be estimated for different households using as many years as possible from the Panel Survey of Income Dynamics (PSID). Hassett, *et al.* (2009) develop a measure of lifetime income following Bull, *et al.* (1994).

[28] Standard Treasury distributional analyses classify families by annual income as measured in the first year of the budget period (Cronin, forthcoming). Such analysis is consistent with measuring tax burdens over the short budget period when the individual income tax code itself is intended to address the cyclical nature of income. Thus, in Treasury's analyses, families who are temporarily poor are treated the same as those who are permanently poor.

gas, home heating oil, and gasoline). As observed in other studies, electricity shares diminish with income. As reported in Table 4, they do so only modestly, from 4.1% to 2.9%. The other three most energy-intensive goods have no discernable pattern or have shares that increase from the poorer to the richer deciles. For example, gasoline expenditure shares increase from the first to the eighth decile, reflecting the ability of higher income groups to afford personal vehicle travel. Overall, the expenditure share for any reasonable aggregation of energy-intensive goods is roughly flat across consumption deciles.

4. Calculations for Policy Alternatives

We proceed to simulate a carbon tax with no rebate and a carbon tax with three revenue-neutral types of rebate. All simulations include an illustrative $100 billion carbon tax,[29] and commodity prices rise relative to factor incomes to cover firms' extra costs of purchasing energy inputs and other energy-intensive intermediate inputs.[30] We assume that the government uses some of the $100 billion revenue to index government transfer programs for those price increases.[31] On average, over 90% of transfer income is indexed in the U.S. The share of transfers that are indexed is lowest for the lowest-income decile and highest for the highest-income decile (Fullerton, *et al.*, 2012). In addition, all simulations index tax parameters to the rising cost of consumption. Indexing of income taxes and transfer programs require government expenditures of $15.5 billion and $8.1 billion, respectively.

The remaining $76.4 billion in carbon tax revenues is an overall burden, or it is used

[29] We scale the price changes for a $25 per metric ton tax to a $100 billion revenue total. This carbon tax corresponds to roughly a 1% increase in the price level, assuming no change in quantities consumed. Horowitz *et al.* (2017) estimate that a $49 per metric ton tax in 2019 would raise net revenues of $194 billion. Our scaling is roughly consistent with that estimate.

[30] Standard Treasury analysis assumes no changes in the price level, as is consistent with revenue estimating assumptions. Instead, the tax is passed back to factor incomes, and relative prices adjust. Carbon-intensive goods become relatively more expensive, and less carbon-intensive goods become relatively less expensive. On a present value basis, without bequests, the two methods are theoretically equivalent. In both cases, transfer income is largely held harmless (and we assume 100% held harmless). When the tax is passed forward, transfer income is indexed for the price level increase; when the tax is passed back onto factor incomes, transfer income is unaffected.

[31] We abstract from monetary policy. Whether output prices rise or factor incomes fall can be equivalent, depending on what happens to real transfers and bequests. Essentially, we assume that all transfers are indexed for inflation when those energy-intensive product prices rise, so that transfer income is held harmless in real terms. Such indexing is statutorily required for SNAP, Social Security benefits, workers' compensation, and veteran benefits. Other transfers are not indexed automatically, but legislation can be reasonably assumed to keep all real transfers constant. Although transfer income is then unchanged in real terms, transfer recipients who consume relatively carbon-intensive commodities still bear a burden from relative price changes due to the carbon tax. And conversely, transfer recipients who consume relatively few carbon-intensive commodities will face lower burdens.

according to one of the three rebate scenarios meant to represent attempts to offset the perceived or actual regressivity of the carbon tax. In effect, we ask: what if policymakers decide to offset the regressivity of the carbon tax by using the revenue to help low-income families cover the extra cost of commodities that constitute a relatively high fraction of low-income family budgets. We assume that all of this remaining $76.4 billion of revenue is: (1) a burden of the carbon tax with no rebate; (2) used to fund a lump-sum rebate equal to $229 per person; (3) used to fund a proportional increase in all transfer program generosity; or (4) used in equal proportions to reduce payroll taxes and to increase social security benefits.

The carbon tax alone might be expected to have a regressive incidence, but we show how this vertical redistribution depends on assumptions. To offset perceived regressivity, many discuss a refundable tax credit per person that functions as a lump-sum rebate (see footnote 5). Because the tax credit is a per capita rebate, larger families receive larger payments that may affect horizontal redistribution. The fixed magnitude of the per capita rebate also ensures that this form of revenue recycling will diminish any regressivity of the carbon tax.

A hypothetical lump-sum rebate has been analyzed in other studies of the vertical distributional effects of a carbon tax. Yet actual policy may instead use existing transfer mechanisms to target the revenue towards low-income family budgets. Therefore, the next simulation increases only existing transfers and the EITC. The $76.4 billion in net carbon tax revenue is enough to increase by 5.9% all real payments for the EITC and most transfers.[32] In fact, either of these first two simulations might represent a preferred mechanism to address the vertical redistribution of the carbon tax, and either might be shown to represent a better mechanism to address horizontal redistribution.

The last simulation uses half of net carbon tax revenues to reduce payroll taxes and half to increase Social Security benefits.[33] Payroll taxes decline 3.9%, and social security benefits increase 3.7%. This simulation is intended to mitigate both regressivity and within-decile outcome heterogeneity. The payroll tax reduction compensates primarily low-wage workers for the higher costs of consumption, whereas the increase in Social Security benefits targets other low-income individuals who are not working. Though this simulation targets both workers and non-workers, it may nevertheless fail to compensate sufficiently some families such as young

[32] Transfers include social security, supplemental security income, wage replacement from workers compensation, SNAP, WIC, LIHEAP, TANF, veteran's benefits, unemployment compensation, and general state assistance.

[33] A proportional cut in payroll taxes paid is equivalent to a cut in the effective tax rate with no change in tax base.

unemployed families. It could also overcompensate some families, particularly those drawing high fractions of their incomes from social security. Such families benefit from the indexing of social security benefits as well as from this direct increase in benefit rates.

5. Results

Consider first the incidence of a carbon tax with no revenue-recycling mechanism, which serves as a baseline against which to compare the three alternative rebate simulations. The additional tax burden in each decile is calculated both as a percent of permanent income (as measured by annual consumption) and as a percent of pre-existing tax burden, as calculated by the TDM to include all tax burdens (individual, corporate, payroll, excise, and estate and gift tax).

Distinct from other analyses of carbon tax incidence, our calculated additional tax burden accounts for indexing of transfer payments and of the individual income tax brackets.[34] This often-overlooked feature of carbon tax implementation diminishes measured regressivity. In fact, for the $100 billion carbon tax, indexing results in $23.6 billion of outlays. As shown here, inclusion of the offsetting effects of indexing and of the ranking by consumption both act to decrease measured regressivity of a carbon tax, even with no revenue-recycling mechanism.

Table 5 displays in the first column the incidence of a carbon tax without the indexing offsets, with families ranked by income, and with tax burden shown as a percent of income. This incidence appears very regressive: the carbon tax is 1.2% of income for the bottom income decile but only 0.52% of income for the top income decile.[35] When applying the indexing offsets, but still ranking by income and still measuring the added burden as a percent of income, measured regressivity diminishes (third column): the carbon tax is 0.71% of income for the bottom decile and 0.45% of income for the top decile. When the added burden is divided by consumption, however, then the carbon tax with offsets is progressive, even when families are still ranked by income (column 4): the carbon tax is 0.5% of consumption for the lowest annual income decile

[34] Dinan (2012) and Fullerton *et al.* (2012) account for indexing of transfers but not of income tax parameters.

[35] As is standard in Treasury distribution tables, the rankings by cash income and consumption have been adjusted by equivalence scales to account for both the number of persons in the family unit and returns to scale in sharing resources within the family unit. Each family's income or consumption is divided by the square root of the number of persons in the family in order to approximate the true level of well-being for the individuals in the family. Thus, a family of four with $40,000 of income is ranked as having the same effective income or consumption as a family of one with $20,000 of income. This adjustment is the same as is used by the Congressional Budget Office (see the methodology appendix in CBO (2016)). For further details on the effects of the family size adjustment, see Cronin *et. al*. (2012). This adjustment only pertains to the ranking of each family. The unit is still the family, and we have equal numbers of families in each decile. The lowest income decile may include more individuals if low-income families include more individuals than do high-income families.

and 0.81% for the top annual income decile.

In the right half of Table 5, families are ranked by consumption. When measuring burden as a percent change in consumption and accounting for indexing of transfers, the carbon tax appears progressive (column 8). The burden is 0.45% of consumption for the lowest consumption decile and 0.80% of consumption for the highest consumption decile.

As shown in Table 6, however, the percentage change in total Federal tax burden is greatest for the poorest families, and this percentage change in tax burden declines monotonically with income.[36] The average family in the first consumption decile has a total tax burden that doubles with the introduction of the carbon tax. The richest families see tax burdens increase by 1.57% on average. We return to a discussion of Table 6 below.

When carbon tax revenues are refunded in a per capita lump-sum payment, as shown in Table 7, the net additional burden as a percent of consumption is even more clearly progressive. In fact, the average family in each of the first seven consumption deciles receives a net reduction in tax. Total taxes borne by the average family in the lowest consumption decile are nearly 700% lower with the carbon tax and rebate. The richest families experience a 1.13% net tax burden increase, or $1,270 per year, equal to 0.58% of their consumption. The average reduction in tax burden for the poorest ten percent of families, $294, is equal to 2.59% of consumption.

However, not all poor families enjoy net tax reductions under this lump-sum rebate. The full distribution of tax changes as a percent of consumption within each consumption decile are presented in Figure 1. This figure includes a red vertical line to denote the boundary between winners and losers, and it shows a blue bar for each one percent range (such as zero up to 1% more tax, or those between 1% and 2% more tax). Seven percent of the poorest families benefit from net tax reductions equal to more than 4% of consumption, while 0.3% bear more burden. The figure shows less heterogeneity in tax changes as a percent of consumption among families in the highest decile. Eighty-five percent of them experience a tax increase of zero to 1% of consumption, while 8% incur extra burdens of 1% to 2% of consumption, and 7% get tax cuts of up to 1% of consumption. Thus, intra-class variation seems to diminish with income.

To investigate this variation further, the penultimate column of Table 7 reports the absolute size of the standard deviation of the tax change. Each family's extra burden reduces

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[36] Tables showing the current-law distribution of federal tax burdens are available on the U.S. Department of the Treasury, Office of Tax Analysis website (https://www.treasury.gov/resource-center/tax-policy/Pages/Tax-Analysis-and-Research.aspx).

consumption, so the standard deviation of the burden is the standard deviation of consumption within the decile. Then, in the last column, the coefficient of variation (CV) of consumption is this standard deviation (SD) divided by mean consumption. While the SD increases from $203 for the lowest decile to $347 for the ninth decile, the CV falls monotonically from 2.7% for the poorest decile to 0.8% for the ninth decile (because consumption in the denominator rises faster than the SD in the numerator).

For the top decile, however, both the SD and CV increase dramatically (to $22,718, or 22% of consumption). This variation within the top decile is difficult to interpret, because the top decile is very heterogeneous and virtually unbounded. Some families in Treasury's confidential tax return data have extremely high income, consumption, and taxes. Thus, the decile's standard deviations are large for income, for energy consumption, and for burdens of a carbon tax.[37] The added variation within this top decile can be compared across reforms, in Tables 6-10, but the added variation in the top decile is not comparable to added variation in other deciles.

The standard deviation of the change in consumption is broadly similar for the carbon tax alone in Table 6 and with the per capita rebate in Table 7. It rises from the first to the ninth deciles (and is very large in the richest decile). But the coefficient of variation within the first five deciles is larger when using carbon revenue for per capita rebates. Even though family size varies in all deciles, this variation in family size implies variation in per capita rebates that is a greater percent of consumption in low consumption deciles. An alternative to per capita rebates could be per family rebates, or rebates that use equivalence scales to offset the burden measured in effective consumption for each person.

Next, Table 8 considers the case where carbon revenues are returned via the same 5.9% increase in the EITC and all transfer benefits (above and beyond indexing of transfers). This reform also results in a progressive distribution of burdens in the second column, where the net burden is negative for eight deciles and positive only for the top two deciles. Because transfers are a larger fraction of income for those in lower deciles, progressivity is greater than for the carbon tax alone in Table 6. The increase in EITC and all transfers is not as progressive as the

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[37] In Treasury's raw data, some families have large negative income and negative taxes because of loss offsets, but most of those families have large wealth and only temporary losses. Because these families are not representative of the lowest income decile, they are not included when calculating results for the lowest decile (but they are included in the totals). Thus, income is bounded from above and from below in all of the first nine deciles, but not in the top decile. Because of this extreme variation within the top decile, many other studies using publicly available data have separated the top 1% of income from the rest of this top decile, but we are not able to do so.

per capita rebate in Table 7. Although transfers are important sources of income in lower deciles, many transfers are not means tested. As a result, the lowest decile receives about 5% of transfer income, whereas the top decile receives 13%. Average family size, in contrast, does not vary much across deciles, so the per person rebate is more progressive.

With the rebate via transfers in Table 8, the largest net tax cuts accrue to families in the third, fourth, and fifth consumption deciles ($212 to $254). In contrast, the poorest families receive only a $109 tax reduction on average, a little more than one-third the size of the tax reduction they received under the lump-sum per capita rebate. The richest families pay $1,090 more in tax on average, equal to a half percent of their annual consumption. This reform avoids average tax changes as a percent of consumption greater than 1%, with the exception of the second decile where the average tax cut is 1.07% of consumption.

Though the rebate via transfers is still somewhat progressive, it is not as progressive as the per capita rebate. Figure 2 shows that this relatively more equal treatment of families across consumption deciles comes at the cost of greater heterogeneity of tax impacts within each decile. Looking across impacts within the poorest decile, 44% of families experience a tax *increase*, even though the long negative tail of this distribution leads to an average net reduction in taxes that is about 1% of consumption. Existing transfers for some poor families are small or zero, so a proportional increase in such transfers adds to heterogeneity of impacts within this group. That is, larger transfers can offset the positive additional carbon tax burden only for some families. While some families face higher carbon tax burdens with no additional transfers, more than 25% of these poorest families enjoy an overall net tax cut equal to more than 2% of consumption.

The average family in each of the first eight consumption deciles enjoys a net tax cut, yet Figure 2 shows that 42% to 66% of families within each of these deciles experience tax increases that are up to 2% of consumption. Comparing Figures 1 and 2 indicates that every consumption decile exhibits more variation in tax treatment under the transfer expansion than under the lump-sum rebate. In fact, every coefficient of variation of consumption is greater with the transfer expansion in Table 8 than with either the lump sum rebate in Table 7 or no rebate in Table 6. In other words, the use of transfers to rebate carbon tax revenue introduces more intra-class variation in consumption than does the carbon tax itself.

Finally, Table 9 shows the carbon tax reform that recycles equal shares of revenues in the form of payroll tax reductions and increases in social security benefits. This package is slightly progressive, yielding a small net tax cut for nine deciles and a tax increase only for the richest decile. Compared to the other reforms, however, it most nearly approximates a proportional tax reform while avoiding the most dramatic intra-class variation in tax changes. It compensates workers for their extra carbon tax burden through the payroll tax reduction, and it compensates retirees with enhanced social security benefits. It does not compensate the nonworking, nonelderly poor, though they benefit from the indexing of transfer income. As a result, the gains to the poor are more limited than in the other proposed reforms, while the losses to the rich are also more limited. As reported in Table 9, the poorest ten percent of families experience an average tax reduction of $18/year, or 0.16% of consumption. The average family in the richest decile is hit by a tax increase of $704, or 0.32% of consumption. Across all deciles, the largest net tax cut for the average family is in the fourth and fifth consumption deciles, each of which receives a tax reduction equal to $113 (or 0.38% and 0.30% of consumption, respectively).

Looking at Table 9 where nine deciles gain, a conventional analysis of the incidence from this third reform might suggest that the vast majority of families benefit from the reform. But further analysis of the heterogeneous tax treatment within each consumption decile reveals the opposite. As shown in Figure 3, a *majority* of families in all deciles experience tax *increases* of up to 1%. In fact, tax increases of up to 2% of consumption apply to 68% of the poorest families, a share for this decile that is greater than for any other decile. At the same time as most families incur very small tax increases, tens of thousands enjoy considerable tax reductions.

Our 322,000 tax families are weighted to represent all 172 million U.S. families. For the 17.2 million in the poorest decile, 92,000 (0.5%) receive tax cuts or benefit increases equal to 5% of consumption or more. Gains greater than ten percent of consumption are enjoyed by 27,000 families. Heterogeneity in tax changes as a percent of consumption declines across consumption deciles in Figure 3. None among the richest families receives a tax cut greater than 5% or an increase greater than 3% of consumption. Outcomes vary less within deciles from this refund than from any other refund considered here, but intra-class variation is still greater than with no refund (except in the top decile).[38] Meanwhile, the CV of consumption is greater than with no refund for all other deciles by at least 50%, and by as much as 230% for the poorest.

The distributional impacts of all these reforms are summarized in Figure 4. For each reform, a whisker bar is used to depict the range from the 10th to 90th percentile of the

[38] In this reform, the coefficient of variation of consumption for the top consumption decile is lower than in any other rebate scenario modeled in this paper, but only barely.

distribution of tax changes within each decile, and an “x” is used to show the median tax change as a percent of consumption. It is evident in the figure that the third proposed reform that rebates revenues through EITC and transfers (CT3 in the figure) induces considerably more variation in tax changes within every group than does any other policy considered. This variation appears to be largest in the third and fourth consumption deciles. The second-most variation in every decile is created by the fourth proposal that rebates revenues through payroll taxes and social security benefits (CT4). In contrast, the carbon tax without rebate (CT1) has the lowest variation in the middle 80th percentile range of impacts among low income groups. The second reform (CT2), with per capita rebate, yields the largest median tax reduction as a percent of income for the poorest 70% of the income distribution. And, among the revenue recycling options, it induces the least additional variation in the middle 80th percentile range of impacts among all groups.

One additional point from Figure 4 is that the richest decile has the shortest whisker bars of any decile, i.e., the least variation between the 10th and 90th percentile of the gain or loss as a percent of consumption within the decile. Yet its standard deviation as a percent of consumption is far higher than any other decile (the CV, for all four reforms). The reason is that the richest ten percent within this richest decile have significantly more consumption and therefore more change in burden than others within the middle 80 percent of the decile.

For all four simulations, Table 10 collects the coefficients of variation of consumption across all ten deciles (from Tables 6-9). Though each of the three revenue-recycling mechanisms considered in this analysis further increases the progressivity of the carbon tax alone, none consistently mitigates the intra-class variation in tax changes introduced by the carbon tax. Indeed, each rebate mechanism increases the CV within most deciles. The carbon tax alone has the lowest variation of within-class tax treatment across the first five deciles. For other deciles, the carbon tax without recycling produces the second-most homogeneous tax treatment. The per capita rebate reduces variation from the carbon tax within each of the top five deciles, and it yields the least variation among the refunding mechanisms for deciles 3-9. Among refunding mechanisms, the payroll tax reduction coupled with increased social security benefits has the lowest within-decile variation for the poorest 20% and richest 10% of households. It comes closest to achieving distributional neutrality on the vertical dimension. The proportional increase in transfers introduces the most within-decile variation in consumption of any simulation.

While the prior literature reviewed above disagrees on “horizontal equity” as a normative goal, that debate was about variation in the *level* of tax burden for those at the same level of well-being, while we show only variation in the *change* of tax burden. We could, for example, show how each reform package changes the standard deviation of total tax burdens within each decile. For two reasons, such calculations are avoided. First, that analysis would have to look at "similar" families within some range of consumption, and yet even a strictly proportional tax would naturally result in a range of tax burdens across that range of consumption. Thus, we see no reason for interest in whether a reform package helps to equalize existing tax burdens of all families across a range of consumption. Second, even if we could identify multiple families with identical means, it is not evident that a reasonable objective for climate policy is to equalize the pre-existing total tax burden. Still, however, some might hold that avoidance of capricious gains and losses is a worthy objective of climate policy.

6. Discussion

A number of studies have analyzed the implications of carbon taxes for vertical redistribution, finding that a carbon tax is regressive and studying complementary tax reforms that would be revenue neutral and preserve progressivity. Our study sheds new light on vertical redistributions from a carbon tax and rebates, and it is the first to study horizontal redistributions. We ask whether complementary tax reforms can help avoid variation in tax treatment among families of similar means. We consider the carbon tax alone and with alternative mechanisms for revenue-neutral rebate of carbon tax revenues, though all simulations index transfer programs and income tax brackets in accordance with federal statutes.

The four simulations evaluated in this paper hardly represent the breadth of potential tax reforms, but our analysis nonetheless provides important insights. First, contrary to the common belief that carbon taxes in the U.S. are regressive, this analysis shows that a carbon tax alone is instead progressive, when vertical effects are measured against consumption as a proxy for permanent income and when accounting for the statutory indexing of transfers and tax brackets.

Second, and perhaps most importantly, we find that a distributional analysis focused on vertical burdens can yield misleading conclusions about welfare changes for pluralities or even majorities of families, including the poorest. Because the usual rebate mechanisms can provide large gains as a percent of consumption for some poor families, an aggregate decile statistic that reports a tax cut for the average family conceals the fact that many or most of them receive small tax increases. Our simulations show that this phenomenon holds not just for the lowest deciles, but across many deciles for which the average tax change is a net reduction. Thus, when interest centers on the tax change experienced by individual families, as opposed to the aggregate impact within a class of families, the micro-level analysis performed here is essential. Policymakers may want to know if a tax reform that delivers large tax cuts to a minority of poor families also leaves most poor families worse off.

Third, horizontal redistributions are *increased* for at least half of the population by any of the three revenue-recycling reforms we consider. Among our simulations, a tradeoff arises between vertical and horizontal redistribution. The reform that rebates half of revenues to payroll tax reductions and half to social security benefits expansion nearly achieves distributional neutrality from a vertical perspective, but it worsens the horizontal disparities in tax treatment relative to the carbon tax alone (for all but the richest ten percent of families). Among revenue-recycling reforms, the per capita rebate has the lowest disparities within most deciles. It is also the most progressive reform, providing relatively large percentage reductions in taxes for the poor at the expense of small percentage increases in taxes for the rich.

Fourth, while variations in tax changes among families in the top consumption decile are difficult to interpret, such large variations surely reflect the limited capacity for means-tested revenue recycling and relatively small rebates in the top decile to offset their considerably larger and more variable tax bills. Yet, while the welfare of the poorest families enjoys a unique place in the standard analysis of vertical redistribution from carbon taxes, the variation in tax changes within a group is not more important among poor than among rich families. The standard deviation of tax change within the richest group is between $22,600 and $22,800 in these simulations, a narrow range that indicates the inability of these simulated reforms to address heterogeneous carbon tax impacts among the rich. But it also suggests that to the extent policymakers are considering reforms to complement a carbon tax, the horizontal disparities within the rich group will not be greatly impacted by whichever reform is pursued, particularly so long as those reforms are intended to be progressive.

Fifth, while Treasury's Distribution Model affords high-fidelity assessments of rebate mechanisms that utilize income channels, the data preclude an exploration of rebate mechanisms based on other family characteristics that could better reduce disparities among families of similar means. In particular, we do not know the age of a family's dwelling nor the energy efficiency of its durable goods, including household appliances and vehicles. We do not observe the characteristics of the family's weather, its commute to work, or its built environment (such as commuter rail and electricity grid infrastructures). These characteristics affect household carbon emissions, and if available they could be used to target household-specific transfers to offset carbon taxes.

While carbon tax rebates based upon these characteristics might be employed to reduce intra-class variation in outcomes, they would also directly affect the efficiency of the carbon tax by reducing the price signal induced by the carbon tax – at least along some margins. For instance, a carbon tax reduces emissions by inducing purchases of energy-efficient appliances or vehicles. If owners of inefficient durables received preferential rebates to compensate for their relatively high carbon taxes attributable to inefficient durables, then their incentives to purchase efficient durables would be reduced. Likewise, families in hot climates use more electricity for air conditioning than families in temperate climates (such as on the coasts). Such families face higher carbon tax bills. If they were compensated for their extra carbon tax burden from their extra use of electricity, then they would have little incentive to invest in home weatherproofing or efficient climate control systems, or to change locations.

To some extent, both tax-change heterogeneity and incentive problems could be alleviated by designing carbon tax rebates that are based upon the mean consumption of families that are similar in location, size, and income category. A family receiving a rebate according to mean carbon emissions of neighbors, for instance, would help reduce air conditioning use because the family's rebate is based not on own usage. Still, a collective action problem emerges where an individual family wants to reduce its own energy use but maintain high use among neighbors. Moreover, to the extent that rebates are based on characteristics of comparable families, then incentives to conserve along dimensions that define comparability are diminished. If the comparable families own single-family homes that consume more energy on average than multifamily housing, then an individual family has no incentive to choose multifamily over single family dwellings, though such a switch might be induced by the carbon tax alone. Similarly, the incentive for families with high air conditioning use to move to cooler climates is diminished so long as their carbon tax rebates are based upon their geographic location.

Finally, one might also consider one-time payments to families that depend on their durable goods holdings or other characteristics at the time of the tax reform, but not thereafter. That is, the introduction of a carbon tax could be complemented by a one-time transfer to families based on age, location, size of their homes, and the vintages of their cars and appliances. This one-time transfer would not affect incentives for future conservation, energy efficiency investments, and purchases of smaller homes in more temperate climates. Such a payment would, in effect, compensate families for the government's "takings" via the carbon tax. The rationale for such a payment, however, is not straightforward. As in any investment decision, rational actors formulate expectations about the values of their investments in alternative states of the world. Such a policy may be inefficient if it insures holders of energy-using capital against their losses, particularly as other families may have made more prudent investments in expectation of a future carbon tax. The prudent family would be punished for holding energy-efficient durables. Thus, the rationale for rebates pegged to consumption patterns may be weak, even if incentive problems could be resolved.

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TABLES AND FIGURES

Table 1: Effects of a Carbon Tax on Fuel Commodity Prices

	Price ($2017) various units[a]	Carbon tax $25/mt CO2[b]	Percent increase due to carbon tax[3]
Commodity prices			
Petroleum	$48.41/bbl	$12.90/bbl	27%
Natural Gas	$2.95/mcf	$1.29/mcf	44%
Coal	$35.16/ton	$46.86/ton	133%

[a] Projections by the Office of Tax Analysis (OTA) of the U.S. Treasury.

[b] Based on on carbon content of 53.12 kg/mcf (natural gas) , 1,874 kg/ton (average coal), 0.43 mt/bbl petroleum). Source for natural gas: http://www.eia.gov/environment/emissions/co2_vol_mass.cfm.
Source for coal and petroleum: https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references.

Table 2: Changes in Consumption Category Prices Due to Carbon Tax

Commodity	**Hassett, *et al*. (2009) ($15/mt, 2005 prices, 2003 consumption)**	**Mathur and Morris (2014) ($15/mt, 2010 prices)**	**Treasury (2016) ($25/mt, 2017 Prices)**
Coal	Nearly 100%		133%
Petroleum	13%		27%
Natural gas	7%		44%
Family consumption good			
food at home	0.70%	0.83%	1.46%
food at restaurants	0.58%	0.47%	0.18%
food at work	0.86%	1.05%	1.46%
tobacco	0.67%	0.64%	0.35%
alcohol at home	0.58%	0.72%	0.36%
alcohol on premises	0.58%		
clothes	0.40%	0.34%	0.57%
clothing services	0.41%	0.22%	1.00%
jewelry	0.43%	0.39%	
toiletries	0.72%		
health and beauty	0.42%	0.55%	0.72%
tenant occupied dwelling	0.31%	0.17%	0.88%
other dwelling rental	0.42%	0.19%	0.71%
furnishings	0.55%	0.74%	0.86%
household supplies	0.71%	0.83%	0.58%
electricity	**12.55%**	**5.21%**	**9.01%**
natural gas	**12.28%**	**18.92%**	**14.83%**
water	0.63%	0.46%	2.45%
home heating oil	**9.56%**	**6.10%**	**14.51%**
telephone	0.26%	0.27%	0.42%
domestic services	0.49%		0.61%
health	0.39%	0.32%	0.55%
business services	0.50%	0.24%	0.52%
life insurance	0.31%	0.06%	0.18%
automobile purchases	0.90%	1.04%	0.56%
automobile parts	0.65%		0.89%
automobile services	0.40%		
gasoline	**7.73%**	**4.72%**	**14.81%**
tolls	0.64%		
automobile insurance	0.31%	0.06%	0.18%
mass transit	0.90%	0.75%	4.61%
other transit	0.62%	1.54%	0.72%
air transportation	1.86%	2.01%	5.46%
books	0.40%	0.35%	0.42%
magazines	0.49%		
recreation equipment	0.42%	0.63%	0.58%
other recreation services	0.51%	0.31%	1.14%
gambling	0.31%		
higher education	0.30%	0.44%	1.32%
preK-secondary educ	0.34%		
other education services	0.30%		
charity	0.41%	0.25%	0.49%

Table 3: Distribution of Cash Income and Consumption, by Consumption Decile

Adjusted Family Consumption Decile	Consumption Range[a]	Percent Distribution of Cash Income	Percent Distribution of Consumption
1[b]	$0 to $11,405	1.0	1.8
2	$11,405 to $15,559	1.9	2.9
3	$15,559 to $19,810	2.8	3.8
4	$19,810 to $24,961	3.8	4.9
5	$24,961 to $31,181	5.2	6.2
6	$31,181 to $38,226	6.8	7.7
7	$38,226 to $46,220	8.8	9.5
8	$46,220 to $57,267	11.3	11.8
9	$57,267 to $75,827	15.4	15.0
10	over $75,827	44.3	36.3
Total[b]		100.0	100.0

[a] The consumption range is shown on a single-person family equivalent basis. Families are ranked according to consumption adjusted for family size, using a square root of family size adjustment. A family of four with $40,000 of consumption would be equivalent to a family of one with $20,000 of consumption.

[b] Families with negative income are excluded from the first decile but included in the total.

Table 4: Consumption Shares by Consumption Categories for Each Decile

Consumption category	All Families	Percent of total consumption, by consumption decile									
		1 poor	2	3	4	5	6	7	8	9	10 rich
food home	10.9	14.0	13.5	12.7	12.2	11.7	11.3	10.9	11.2	11.0	9.9
food at restaurants	4.2	2.5	3.2	3.6	3.7	3.8	3.9	4.0	4.2	4.3	4.6
food at work	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
tobacco	0.8	2.6	2.4	2.0	1.6	1.2	1.0	0.8	0.7	0.6	0.2
alcohol	0.7	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.8
clothes	1.5	1.0	1.3	1.6	1.7	1.5	1.4	1.4	1.4	1.3	1.7
clothing services	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
health and beauty	0.6	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7
tenant occupied dwelling	18.6	19.6	20.4	19.4	19.3	18.8	18.8	18.1	17.6	17.8	19.0
other dwelling rental	0.8	0.1	0.2	0.2	0.2	0.3	0.4	0.6	0.8	0.9	1.3
furnishings	1.0	0.6	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.4
household supplies	0.8	0.3	0.4	0.6	0.5	0.5	0.6	0.7	0.7	0.8	0.9
electricity	**3.2**	**4.1**	**4.1**	**3.9**	**3.6**	**3.5**	**3.4**	**3.1**	**3.3**	**3.3**	**2.9**
natural gas	**0.9**	**0.9**	**1.0**	**1.1**	**1.1**	**1.0**	**1.0**	**1.0**	**1.0**	**0.9**	**0.9**
water	1.2	1.2	1.1	1.2	1.2	1.1	1.1	1.2	1.3	1.2	1.1
home heating oil	**0.3**	**0.2**	**0.2**	**0.2**	**0.4**	**0.4**	**0.4**	**0.3**	**0.3**	**0.3**	**0.4**
telephone	2.8	2.8	3.0	3.1	2.8	2.8	2.8	2.7	2.8	2.9	2.6
domestic services	1.8	1.2	1.3	1.6	1.6	1.5	1.5	1.8	1.8	1.8	2.0
health	17.3	31.6	26.2	23.1	23.2	24.2	23.8	22.3	19.9	17.4	9.8
business services	1.1	0.4	0.4	0.5	0.6	0.7	0.7	0.7	1.0	1.6	1.3
personal insurance, pensions	9.8	3.5	5.3	6.8	7.0	7.3	8.0	9.1	9.5	9.9	12.3
automobile purchases	2.4	0.4	0.4	0.6	0.9	0.9	0.9	1.0	0.9	2.0	4.6
automobile parts	1.6	0.6	1.0	1.4	1.3	1.3	1.5	1.6	1.8	1.8	1.7
gasoline	**5.5**	**4.0**	**5.0**	**5.8**	**5.7**	**5.5**	**5.4**	**5.8**	**6.0**	**5.6**	**5.4**
automobile insurance	2.0	1.3	1.5	1.9	2.0	2.0	1.9	2.0	1.9	2.0	2.0
mass transit	0.5	0.4	0.3	0.3	0.3	0.4	0.5	0.6	0.5	0.5	0.5
other transit	0.7	0.4	0.4	0.5	0.8	0.8	0.7	0.7	0.7	0.6	0.9
air transportation	0.6	0.4	0.6	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8
reading	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3
recreation equipment	3.1	2.8	2.8	2.8	2.7	2.9	3.0	2.9	3.2	3.4	3.2
other recreation services	0.9	0.3	0.4	0.5	0.5	0.6	0.6	0.8	0.9	0.9	1.2
education	1.0	0.4	0.5	1.1	1.5	1.0	0.7	0.7	0.5	0.6	1.5
charity	2.7	1.2	1.3	1.4	1.4	1.7	1.9	2.1	2.8	3.0	3.5
Total	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

Table 5: Comparing Carbon Tax Distributions Ranked by Income and Consumption with and without Indexing Offsets

Decile	Ranked by Adjusted Family Cash Income				Ranked by Adjusted Family Consumption			
	without indexing offsets		with indexing offsets		without indexing offsets		with indexing offsets	
	(1) Tax Change as % of income	(2) Tax Change as % of consumption	(3) Tax Change as % of income	(4) Tax Change as % of consumption	(5) Tax Change as % of income	(6) Tax Change as % of consumption	(7) Tax Change as % of income	(8) Tax Change as % of consumption
1	1.21	0.86	0.71	0.50	1.08	0.89	0.54	0.45
2	0.99	0.97	0.54	0.52	1.03	0.96	0.58	0.54
3	0.94	0.99	0.49	0.52	0.95	1.01	0.55	0.58
4	0.89	0.99	0.50	0.55	0.89	1.00	0.54	0.61
5	0.83	0.97	0.52	0.61	0.82	0.97	0.55	0.65
6	0.78	0.96	0.56	0.69	0.76	0.96	0.56	0.71
7	0.76	0.97	0.58	0.74	0.74	0.98	0.57	0.75
8	0.73	0.99	0.57	0.78	0.72	1.00	0.55	0.76
9	0.66	0.97	0.52	0.78	0.65	0.96	0.50	0.74
10	0.52	0.94	0.45	0.81	0.53	0.94	0.46	0.80
Total	0.67	0.96	0.51	0.73	0.67	0.96	0.51	0.73

Notes: The carbon tax is scaled to hit $100 billion without offsets. The tax is assumed to be passed forward to consumers in the form of price increases on consumption goods, with the relative price increase of each good dependent on the carbon intensity of its inputs. Since total consumption is about $10 trillion, the $100 billion carbon tax increases the general price level by about 1%. Government transfers and certain parameters in the individual income tax are indexed. As a result, the general price increase of 1% increases government transfer expenditures by about $8 billion and decreases individual income tax receipts by about $15.5 billion. Together, all else equal, these two offsets would be expected to decrease carbon tax revenue by roughly $23.5 billion.

Table 6: Incidence by Decile of Carbon Tax, with Indexing Offsets and No Rebates

Consumption Decile	Average change in tax burden	Tax change as a % consumption	Tax change as a % of current-law tax[a]	Standard deviation of burden	Coefficient of variation of consumption (in %)
1	$51	0.45	119.0	$64	0.86
2	$95	0.54	98.6	$103	1.08
3	$134	0.58	20.6	$152	1.24
4	$178	0.61	9.2	$195	1.26
5	$245	0.65	5.8	$213	1.12
6	$330	0.71	4.3	$250	1.06
7	$434	0.75	3.8	$342	1.21
8	$544	0.76	3.2	$360	1.05
9	$674	0.74	2.5	$422	0.96
10	$1,757	0.80	1.6	$22,725	22.05

[a] Current law includes Treasury's assumptions about the incidence of all Federal taxes: individual income tax, corporate income tax, payroll taxes, excises and customs duties, and estate and gift taxes.

Table 7: Incidence by Decile of Carbon Tax, with Indexing Offsets and Per Capita Rebate

Consumption Decile	Average change in tax burden	Tax change as a % consumption	Tax change as a % of current law tax[a]	Standard deviation of burden	Coefficient of variation of consumption (in %)
1	-$294	-2.59	-691.55	$203	2.69
2	-$325	-1.86	-336.71	$236	2.47
3	-$297	-1.29	-45.87	$262	2.14
4	-$258	-0.88	-13.34	$281	1.82
5	-$206	-0.55	-4.91	$252	1.32
6	-$125	-0.27	-1.64	$237	1.01
7	-$33	-0.06	-0.29	$276	0.98
8	$71	0.10	0.42	$280	0.81
9	$204	0.23	0.76	$347	0.79
10	1,270	0.58	1.13	$22,718	22.04

[a] Current law includes Treasury's assumptions about the incidence of all Federal taxes: individual income tax, corporate income tax, payroll taxes, excises and customs duties and estate and gift taxes.

Table 8: Incidence by Decile of Carbon Tax, with Indexing Offsets and Proportional Increase in EITC and Transfers

Consumption Decile	Average change in tax burden	Tax change as a % consumption	Tax change as a % of current law tax[a]	Standard deviation of burden	Coefficient of variation of consumption (in %)
1	-$109	-0.96	-255.92	$233	3.09
2	-$187	-1.07	-193.70	$339	3.55
3	-$224	-0.97	-34.63	$469	3.83
4	-$254	-0.87	-13.15	$613	3.98
5	-$212	-0.56	-5.05	$736	3.86
6	-$108	-0.23	-1.42	$813	3.46
7	-$31	-0.05	-0.27	$913	3.23
8	-$5	-0.01	-0.03	$1,022	2.97
9	$59	0.06	0.22	$1,155	2.61
10	$1,090	0.50	0.97	$22,773	22.10

[a] Current law includes Treasury's assumptions about the incidence of all Federal taxes: individual income tax, corporate income tax, payroll taxes, excises and customs duties and estate and gift taxes.

Table 9: Incidence by Decile of Carbon Tax, with Indexing Offsets, Half of Revenue to Payroll Tax Reduction and Half to Social Security Benefits Increase

Consumption Decile	Average change in tax burden	Tax change as a % consumption	Tax change as a % of current law tax[a]	Standard deviation of burden	Coefficient of variation of consumption (in %)
1	-$18	-0.16	-41.68	$153	2.03
2	-$44	-0.25	-45.31	$228	2.39
3	-$74	-0.32	-11.39	$309	2.52
4	-$113	-0.38	-5.84	$388	2.52
5	-$113	-0.30	-2.68	$437	2.29
6	-$89	-0.19	-1.17	$471	2.00
7	-$70	-0.12	-0.61	$543	1.92
8	-$81	-0.11	-0.47	$593	1.72
9	-$86	-0.09	-0.32	$664	1.50
10	$704	0.32	0.63	$22,616	21.94

[a] Current law includes Treasury's assumptions about the incidence of all Federal taxes: individual income tax, corporate income tax, payroll taxes, excises and customs duties and estate and gift taxes.

Table 10: Coefficient of Variation (in %), by Decile for Each Carbon Tax Simulation

Consumption Decile	No rebate	Per capita rebate	Proportional increase in transfers	Payroll tax reduction and Social Security benefits increase
1	0.86	2.69	3.09	2.03
2	1.08	2.47	3.55	2.39
3	1.24	2.14	3.83	2.52
4	1.26	1.82	3.98	2.52
5	1.12	1.32	3.86	2.29
6	1.06	1.01	3.46	2.00
7	1.21	0.98	3.23	1.92
8	1.05	0.81	2.97	1.72
9	0.96	0.79	2.61	1.50
10	22.05	22.04	22.10	21.94

Figure 1: Distribution of Tax Changes for Carbon Tax with Per Capita Rebate

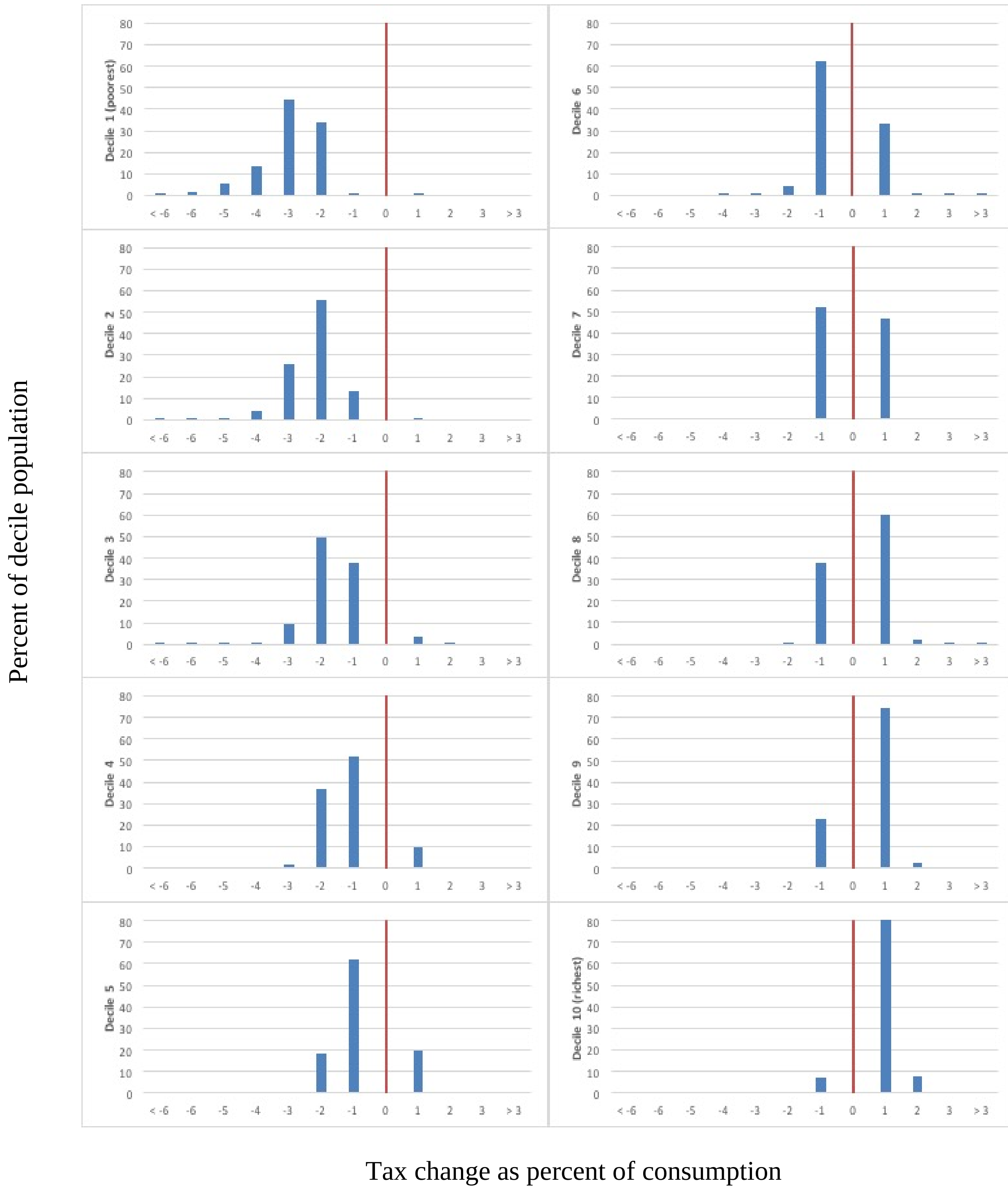

Figure 2: Distribution of Tax Changes for Carbon Tax with Proportional Increase in Transfers

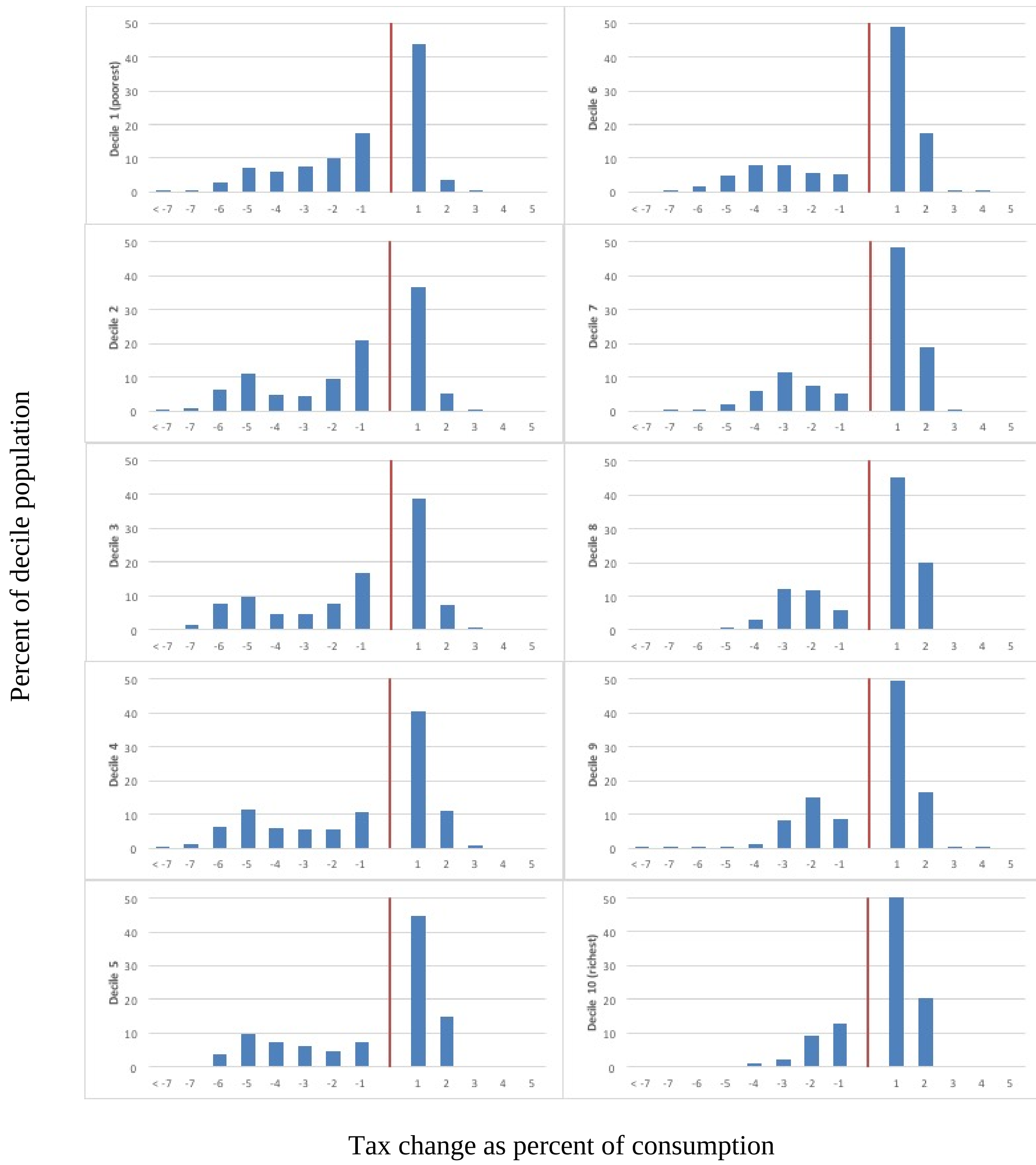

Figure 3: Distribution of Tax Changes for Carbon Tax with Payroll Tax Reduction and Social Security Benefits Increase

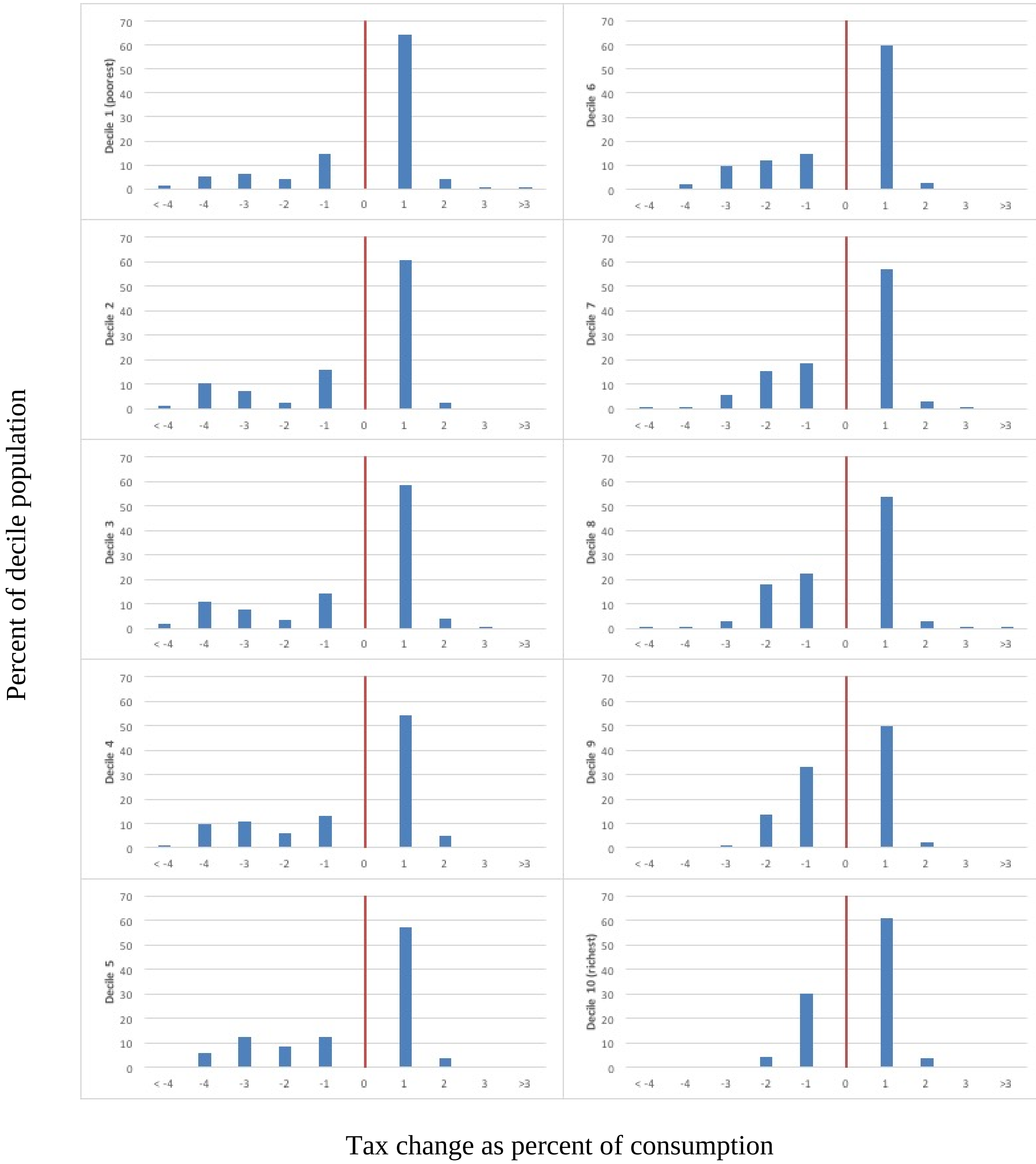

Figure 4: Distribution of the Change in Tax Burdens as a % of Consumption by Decile, for a Carbon Tax with and without Rebates (Range of each Bar is 10th to 90th percentile)