CARBON TAX REBATES AND REDISTRIBUTION

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ABSTRACT

A number of studies have analyzed the implications of carbon taxes for vertical equity, explored conditions under which a carbon tax is regressive, and studied complementary tax reforms that would be revenue neutral and preserve progressivity. But no previous research has explored the extent to which complementary tax reforms can both achieve vertical equity and avoid variation in tax treatment among families of similar means. We consider three alternative mechanisms for revenue-neutral carbon tax reforms that utilize existing tax and transfer programs to mitigate regressivity and try to minimize disparities in outcomes within income classes. We find that aggregate statistics on average tax changes for each decile conceal considerable heterogeneity in tax treatment. Particularly, reforms that yield average reductions to low-income groups in fact deliver small tax increases to most low-income families. We also find that a carbon tax is not regressive when transfers and income tax brackets are properly indexed. We find that the modeled reforms impose a tradeoff between preservation of vertical equity and horizontal equity.

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For the reduction of carbon emissions, economists often show that market-based pricing policies such as carbon taxes and tradable permit programs can achieve higher overall welfare than commonly-employed mandates such as renewable-fuel standards or energy efficiency standards. Despite their greater economic efficiency, however, these pricing policies have found little favor for a variety of reasons. Policymakers may not trust the market to allocate resources efficiently, and of course they have objectives of their own. Another reason – and a motivation of this paper – is that policymakers fear the distributional consequences of carbon pricing policies, particularly their 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.

In response, economists point out that measured regressivity depends on the how household income is defined and measured, and on the consumer and producer shares of tax incidence, as well as other features of such policies. Moreover, they note that distributional objectives can be attained via complimentary changes to government taxes and transfers. The distributional effect of a regressive carbon tax in the U.S., for instance, can be neutralized by increasing the progressivity of income taxes or by increasing 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." The implication is that efficiency and distributional objectives can be independently pursued.

While vertical equity between high- and low-income groups can perhaps be preserved by offsetting changes in tax and transfer programs, horizontal equity between families of comparable incomes may be more problematic. Because of heterogeneity in income sources and expenditures within an income group, any package of reforms is likely to create winners and losers. Poor retired workers' losses from a carbon tax cannot be offset by an expanded EITC or reduced income tax. Even if retired workers could be compensated via social security benefits expansion, poor families in harsh climates would still bear a higher carbon tax burden than families of similar means residing in temperate areas where energy use for home temperature control is limited. And any attempt to target rebates to those who spend more on energy may implicitly encourage the use of energy, effectively eviscerating the efficiency benefits of the carbon tax. Thus, horizontal equity may be difficult to preserve with the introduction of carbon pricing regimes.

This paper assesses the capacity of existing transfer mechanisms to achieve vertical and horizontal equity 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., 2010). We show the extent to which income-targeted transfers undercompensate some and overcompensate others. In particular, we find that aggregate statistics on decile tax changes, such as the average tax change, conceal considerable heterogeneity within income deciles. Because of large left tails of the tax change distribution, some reforms that produce average reductions in tax burdens across most deciles nevertheless yield small tax *increases* to majorities in each decile. Moreover, we find among the modeled tax reforms a tradeoff between vertical equity and horizontal equity preservation.

Economists have engaged in some vociferous debate about the merits of horizontal equity as a policy criterion, with some concluding it is at least as pivotal a policy criterion as vertical equity, and yet virtually no existing research characterizes the magnitudes of horizontal redistributions stemming from a carbon tax and potential revenue recycling mechanisms. Poterba (1991) first demonstrated the expected disparate effects of energy taxes across households of similar means, by documenting considerable variation in their gasoline expenditures. Only Rausch, Metcalf, and Reilly (2011) have estimated variation in carbon tax burdens within income groups (though they did not look at effects of transfers intended to offset those burdens). To our knowledge, no existing research explores the extent to which carbon tax redistribution can be mitigated by reforms to tax and transfer programs.

The major reason for this omission is the absence of a publicly accessible dataset that provides the necessary information to evaluate the horizontal equity implications of 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. Fortunately for our purposes, however, the U.S. Treasury Department 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.

Our project will make use of the U.S. Treasury's merged file of 300,000 tax returns plus 22,000 non-filer "information returns."[1] First, each of these 322,000 returns is matched to a similar family in the CEX, and the CEX family's 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). Second, we use estimates for effects of energy taxes on the market price of each consumption good (similar to estimates in Metcalf 2009 or Mathur and Morris, 2014). These price effects are applied to the detailed expenditures of each family in Treasury's merged dataset in order to calculate the burden on each of 322,000 families, and, thus, to characterize both vertical and horizontal distributions of burdens. Third, the estimates are used to assess how each family's energy tax burden is offset by changes to taxes and transfer programs, showing net gains or losses to each income group and within each group. If a transfer mechanism can prevent extreme or capricious burdens, then policymakers can take advantage of the efficiency afforded by market mechanisms like taxes that minimize the cost of reducing carbon emissions.

Our analysis is limited by the fact that our merged dataset does not include information on each family's geographic location, housing and appliance vintages, or commuting distance to work, characteristics thought to influence family exposure to carbon taxes. Thus, our data preclude empirical analysis of compensation schemes tied to household characteristics other than income sources and transfer recipiency. Nevertheless, we discuss the equity and efficiency implications of family-specific compensation schemes based on these family characteristics.

This paper proceeds in the following section with a review of existing literature on the distributional impacts of carbon taxes and on the policy interest in vertical and horizontal equity. Section 3 describes the data and methods used to simulate carbon taxes and compensation programs. Section 4 describes simulations, while section 5 shows distributional impacts, and Section 6 considers policy implications of this analysis and alternative compensation schemes whose formal analysis is beyond the scope of this paper.

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[1] Treasury's Distribution Model uses only non-dependent returns, not yet weighted. The analysis below applies a weight to each return, where the weights vary from 1 to 1,000. The resulting weighted dataset represents 172 million U.S. families.

1. Overview of Distributional Effects of Carbon Policies and Rebates

Conventional wisdom holds that carbon pricing programs like tradable permit systems or carbon taxes burden the poor relative to the rich (e.g., Metcalf, 2009; Rausch, Metcalf, and Reilly, 2011; Williams et al. 2015). Consumer expenditure data from the U.S. and many European countries demonstrate that low-income households devote greater shares of their incomes to energy purchases than do rich households (Pizer and Sexton 2016, Flues and Thomas 2015). A relatively recent but robust literature has demonstrated that distributional concerns inspired by such comparisons of expenditure shares across income groups may be misplaced, however, or at least exaggerated. Measures of regressivity are diminished when evaluated according to proxies for lifetime income such as annual expenditures, in contrast to the use of annual incomes that fluctuate with temporary spells of unemployment, changes in health status and family conditions, other shocks, and well-known lifecycles in earnings and asset accumulation (Poterba 1989, Bull, Hassett, and Metcalf 1994, Sterner 2012). According to the permanent income hypothesis, the smoothing of household consumption over time implies that a measure of annual consumption does a better job than annual income as a proxy for permanent income (Friedman 1957). 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 mechanisms to offset regressivity using the existing tax code and existing transfer programs, as well as lump sum transfers to households. For instance, by refunding merely 11% of revenues, the poorest quintile of households can be fully compensated—on average—for the added cost of a $15 per ton tax on carbon dioxide emissions (Mathur and Morris 2014). Metcalf (2009) develops a revenue-and-distribution-neutral tax reform package that raises $88 billion from a $15 tax per ton of carbon dioxide emissions and returns it through an earned income tax credit 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 system. Efficiency would dictate that carbon tax revenues be used to reduce the most distorting taxes, which tend to be progressive.[2] Carbon tax

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

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 equity impacts with little attention to horizontal equity. 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 households direct nearly 20% of their total expenditures toward electricity, while other poor households incur no electricity expenses at all. This variation is induced by differences in household size, 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 can introduce heterogeneous carbon tax burdens among otherwise similar households, Williams et al. (2014) found in a general equilibrium setting that variation in carbon tax burdens is more a consequence of differences in income sources than in energy uses. Heterogeneity due to these differences in income sources is potentially easier to remedy without inducing efficiency losses because of existing income reporting requirements and opportunities to target refunds according to income sources. Nevertheless, in practice, this targeting too can be complicated because of variation in benefits recipiency within income groups. For instance, only 32% of families in the lowest-income decile receive the EITC benefits that Metcalf (2009) would expand to address carbon tax regressivity.[3] Alternatively, burdens might be offset by expansions in transfer 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.[4]

High rates of payroll tax liability and of social security recipiency among most income

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[3] Benefit recipiency rates based on authors' analysis of U.S. Treasury data.

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

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 difficulty 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 preserves horizontal equity – particularly among the lowest-income families– is not straightforward.

While policy interest in vertical equity follows directly from the concept of diminishing marginal utility of income within the utilitarian social welfare framework (e.g., Bentham, 1802), the theoretic foundation for horizontal equity is less straightforward and subject to debate among economists. Stiglitz (1982) showed that horizontal equity does not derive from the social welfare or utilitarian criterion and that it may contravene conventional welfare maximization and countermand the Pareto principle, a critique shared by Kaplow (2000). Pursuit of horizontal equity may require the diminution of some individual welfares in order to achieve common outcomes, and it may provide preference for common outcomes over those in which individual welfare levels are higher but heterogeneous. Kaplow (1989, 1992, 1995, 2000) argues that the principle bears no independent normative content and that it 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).

By Kaplow's definition of equals "in all relevant respects," a carbon tax would preserve horizontal equity by treating equally 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, asking rhetorically, "if there is no specified reason for discriminating among unequals, how can there be a reason for avoiding discrimination among equals." The notion that equals should be treated equally by policy has intuitive appeal and popularity among economists (Atkinson and Stiglitz 1980, Stiglitz 1982). Sidgwick (1874) argued that horizontal equity should 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 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 "from behind the veil." 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 suitably broadening the definition of social welfare. Auerbach and Hassett (2002) give horizontal equity independent normative content by ascribing to 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 and deviations in "global" income, horizontal equity becomes a distinct component of inequality aversion. That individuals value not only their own levels of incomes but also their relative incomes is a phenomenon documented by Easterlin (2003). Thus, changes in relative incomes imply welfare losses.[5]

Kaplow (1989, 1995, 1992, 2000), however, wonders what is so sacrosanct about the original distribution of income within an income group that it cannot be changed. He argues that preference for the original or *ex ante* outcomes over *ex post* outcomes (after a policy change) is morally arbitrary. Horizontal equity implicitly favors pre-intervention outcomes based on "ability luck" over post-intervention outcomes that may differ due to "administrative luck."

2. Treasury's Distribution Model

The Office of Tax Analysis of the U.S. Department of the Treasury has constructed a dataset and model we will call Treasury's Distribution Model (TDM), and we use it in this paper to estimate the equity impacts of a U.S. carbon tax and of alternative rebate mechanisms. In this section, we describe Treasury's efforts on this model in four main steps (summarized here, and described

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[5] See, e.g. Atkinson (1980), Feldstein (1976), Rosen (1978), Plotnick (1981), and King (1983).

further below).[6] First, for the TDM, each family's total annual consumption spending is estimated using individual income tax returns and information returns for each of 322,000 representative families (weighted to generate a population of 172 million families). Second, each tax family is matched to a similar family in U.S. Consumer Expenditure Survey (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 their expenditure on each category. Third, the direct and indirect impacts of a carbon tax on each of the commodity prices is estimated using a partial equilibrium, input-output model. And finally, post-carbon-tax expenditures are related to pre-tax expenditures by assuming consumption quantities are unchanged (so each expenditure must increase by the amount that good's price increases).[7] 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.[8] These returns are supplemented with tax records for similarly sampled non-deceased non-filers using "information returns". These information returns include, among others, Internal Revenue Service forms W-2 and Social Security Administration forms 1099. 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

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[6] See Cronin (2016, forthcoming) for a complete description of Treasury's Distribution Model.

[7] 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).

[8] 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 than each single-family household, all else equal.

million people, or 172 million families, 28 million of whom do not file an individual income tax return.[9] 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 sources.[10] 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.[11] 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).[12] Savings and dis-savings are imputed from the Survey of

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[9] The tax sample has two components: first is a random sample of social security number (SSN) ending-digits (the last 4 digits are random, and the sample includes 10 sequences, weight of 1000); 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.

[10] 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 (2016, forthcoming) for a complete description of the income imputations in the TDM.

[11] 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.

[12] 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

Consumer Finances (SCF).[13]

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.[14] 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%.

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 percent to top 10 percent). 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. 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

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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.

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

[14] The general idea of this calculation is to start with family total consumption as measured from the tax data and then impute shares of consumption as found in the CEX. To measure consumption using tax data, the TDM starts with taxable income from the return and adds some items of income that were not taxable but could be used to make out-of-pocket expenditures (e.g. transfers such as food stamps). It then subtracts an estimate of savings from this estimate of consumption and imputes shares of consumption for each expenditure using the CEX. TDM then adds consumption items included in Treasury's cash income measure that are not taxable and that do not require out-of-pocket expenditures. These consumption items are not included as expenditures in the CEX, but include employer-sponsored health insurance, other employer fringe benefits, and the insurance value of Medicare and Medicaid..

categories by assuming that tax family has the same the expenditure shares as the family in the matched CEX record. To these imputed expenditures are added consumption from employer fringe benefits that do not include out of pocket costs, 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, so most income items have third-party verification. This verification reduces income measurement error that may arise from self-reporting bias, top coding, or small sample size in survey data.

The carbon tax burden for each family is readily estimated, given its estimated consumption amount and the estimated price changes for each of the 33 consumption goods. To estimate 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.[16] The carbon tax 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 estimate 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 are 44% higher (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 a more recent year (expected to continue into 2017).[17]

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

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

[17] 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.

the U.S. Bureau of Economic Analysis's 2007 benchmark input-output tables. These tables 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. This assumption results in commodity price increases across the 389 industries, which leads to another round of price hikes.[18] 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 transportation, retail, and wholesale trade.[19] The price changes for the 389 commodities are then mapped to changes in the 33 consumption goods as defined in the CEX and imputed to the TDM.[20] The estimated price changes from the carbon tax are reported in Table 2, along with the corresponding price changes calculated in previous studies. Electricity prices climb 9%, but most indirect price increases are less than 1%. The greatest indirect price changes for non-energy outputs are for mass transit and air transportation, which increase 4.6% and 5.5%, respectively.

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 accounting income or taxable income). Yet annual income may not be a good way to determine who is doing well and who is doing poorly. For example, the group with the lowest annual income may be an aggregation of very dissimilar individuals, including: (1) young workers who know they will earn much more over their careers, (2) the elderly who did

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

[19] 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 aggregated to obtain the final purchasing price.

[20] 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).

earn much more over their careers, (3) self-employed individuals with variable income who happen to be observed in a year with low annual income, and (4) those who are perennially poor. Yet the policy concern for these four types of individuals may differ. More generally, annual income is subject to spells of unemployment, health problems, and changes in 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.[21] Therefore a more meaningful measure of well-being might be a measure such as permanent income or lifetime income. Yet, such measures can be very difficult to estimate.[22]

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.[23]

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

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 richest ten percent of families, as defined

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[21] 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 relating household consumption to typical lifetime consumption profiles for similar households.

[22] Fullerton and Rogers (1994) and other more recent 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 a variety of different households using as many years as possible from the Panel Survey of Income Dynamics (PSID).

[23] Standard Treasury distributional analyses classify families by annual income as measured in the first year of the Budget period (Cronin, 2016). Such analysis is consistent with measuring tax burdens over the shorter budget period time horizon when the individual income tax code itself is intended to address the cyclical nature of income. Thus, in Treasury's analysis, families who are temporarily poor are treated the same as those who are permanently poor.

by annual consumption, accrue 44.3% of total cash income and consume 36% of all goods and services. The poorest 10% of families have only 1% of income and consume almost 2% 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. Consumption shares for health decline markedly across deciles, from 31.6% for the poorest ten percent of families to 17.4% for the richest families. Total food consumption shares vary less, from 14% for the poorest ten percent of families to 11% for the richest families. Direct energy expenditures, including electricity, natural gas, and gasoline, comprise in total less than 11 percent of overall consumption across deciles. As has been observed in other studies, electricity shares diminish in income. As reported in Table 4, they do so only modestly from 4% to 3%. Gasoline expenditure shares increase with income, reflecting the ability of higher income groups to afford personal vehicle travel. Interestingly, mass transit constitutes less than 1% of expenditures across deciles.

4. Calculations for Policy Alternatives

We proceed to simulate three revenue-neutral tax reforms. All include an illustrative \$100 billion carbon tax.[24] In all simulations, we assume here that commodity prices rise relative to factor incomes to cover firms' extra costs of purchasing energy inputs and other energy-intensive intermediate inputs.[25] We also assume that the government uses some of the \$100 billion revenue to index those government transfer programs for those price increases.[26] On average, over 90 percent of transfer income is indexed in the U.S. The share of transfers that are

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[24] 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 percent increase in the price level, assuming no change in quantities consumed.

[25] 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.

[26] We do not assume anything about whether monetary policy allows output prices to rise, or if instead factor incomes fall. These can be equivalent, however, if higher product prices imply lower real factor returns, depending on what happens to real transfers. Essentially, we assume that transfers are indexed for inflation when those energy-intensive product prices rise, so that transfer recipients are 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 those transfers constant in real terms.

indexed is lowest for the lowest income decile and highest for the highest income decile (Fullerton, Heutel, Metcalf (2012). In addition, all simulations index tax brackets to the rising cost of consumption. Indexing of income taxes and transfer programs induce expenditures of $15.5 billion and $8.1 billion, respectively.

The remaining $76.4 billion in carbon tax revenues is assumed to be used according to three different alternatives, each meant to represent an attempt 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 try to help low-income families to cover the extra cost of commodities that constitute a relatively high fraction of low-income family budgets. We assume this remaining revenue is used to fund either (1) a lump-sum rebate equal to $229 per person, (2) a proportional increase in all transfer program generosity, or (3) half of it is used for a payroll tax reduction and half is used for social security benefits increase. For comparison, we also show effects of a carbon tax with indexed transfers but with no other rebate or revenue recycling.

The first simulation recycles revenue by a refundable tax credit per person that functions as a lump-sum rebate and is expected to reduce the regressivity of the carbon tax. Because the tax credit is a per capita rebate, larger families receive larger payments that may help address horizontal equity. The fixed magnitude of the per capita rebate also ensures that this form of revenue recycling will diminish any regressivity of the carbon tax.

That hypothetical lump-sum rebate has been analyzed in other studies of vertical distributional effects of a carbon tax, but actual policy may instead try to make use of existing transfer mechanisms to target the revenue towards low-income family budgets. Therefore, the second simulation increases only existing transfers. The $76.39 billion in net carbon tax revenue is enough to increase by 5.9% all real payments for the EITC and most transfers.[27] 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 third simulation uses half of carbon tax revenues to reduce payroll taxes and half of

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

revenues to increase Social Security benefits. 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 nonworkers, it may nevertheless fail to compensate sufficiently some families such as young unemployed families. It could also overcompensate some families, particularly those drawing full incomes from social security. Such families benefit from the indexing of social security as well as from the increase in benefit rates.

5. Results

We begin by considering the incidence of a carbon tax with no revenue-recycling mechanism, as a baseline against which to compare the three alternative rebate simulations. We compare the calculated added tax burden in each decile to their permanent income (as measured by annual consumption), and we also calculate this added federal tax burden as a percent of pre-existing federal tax burden, calculated by the TDM to include all taxes (individual, corporate, payroll, excise, and estate and gift tax).

Distinct from other analyses of carbon tax incidence, our calculated added tax burden accounts for indexing of transfer payments and of the individual income tax brackets. This often-overlooked feature of carbon tax implementation diminishes observed regressivity. In fact, for the $100 billion carbon tax, indexing results in $23.6 billion of outlays principally to benefit recipients. As shown in Table 5, the inclusion of the offsetting effects of indexing and of the ranking by consumption both act to decrease observed regressivity in a carbon tax with no revenue-recycling mechanism. The incidence of the carbon tax without the indexing offsets, ranked by income, and shown as a percent of income (first column) appears very regressive: the carbon tax is 1.2 percent of income for the bottom income decile but only 0.52 percent of income for the top income decile.[28] When applying the offsets but still ranking by income and still

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[28] As is standard in Treasury distribution tables, the rankings by cash income and consumption have been adjusted for family size, using a square root adjustment to account for both the number of persons in the family unit and returns to scale in sharing resources within the family unit. A family of 4 with $40,000 of income is ranked the same as a family of one with $20,000 of income. This adjustment is the same as is used by the Congressional

measuring regressivity as a percent change in income, measured regressivity diminishes (third column): the carbon tax is 0.71 percent of income for the bottom decile and 0.45 percent of income for the top decile. However, if regressivity is measured as a percent change in consumption (as a proxy for permanent income), the carbon tax with offsets, even ranked by income, no longer appears regressive, but progressive (column 4): the carbon tax is 0.5 percent of permanent income for the lowest income decile and 0.81 percent for the top income decile.

Ranking by consumption, including the indexing offsets and measuring regressivity as a percent change in consumption is what we would argue is the right metric; in this case, the carbon tax appears progressive: the carbon tax is 0.45 percent of consumption for the lowest consumption decile and 0.73 percent of consumption for the highest consumption decile.

As shown in Table 6, however, the percentage change in tax burden is greatest for the poorest families, and this percentage change in tax burden declines monotonically with income.[29] The average family in the first consumption decile has a tax burden that doubles with the introduction of the carbon tax. The richest families see tax burdens increase by 1.57% on average.

By refunding carbon tax revenues in a per capita lump-sum payment, in Table 7, the additional burden as a percent of consumption is even more clearly progressive. In fact, the average family in the first seven consumption deciles experiences net reductions in taxes. 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 tax burden reduction among 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 has a red vertical line to denote the boundary at zero added tax, 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 tax

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Budget Office (see the appendix on methodology CBO (2016)). For further details on the effects of the family size adjustment, see Cronin et. al. (2012).

[29] 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).

reductions equal to more than 4% of consumption, while 0.3% bear more tax burden. The figure shows less heterogeneity in tax changes as a percent of consumption among families in the highest consumption 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% incur tax reductions of of less than 1% of consumption. By this measure, intra-class variation seems to diminish with income. However, as Table 7 reports, the standard deviation of the magnitude of tax changes increases with income. The average tax increase for the richest group is 0.58% of consumption, but this number conceals dramatic variation in the magnitude of tax impacts among these families. The standard deviation increases with income and is $22,718 for the top decile, likely because the standard deviation in income is highest in the top decile.[30] Normalizing the standard deviation by average decile consumption demonstrates that the coefficient of variation for consumption is greater in the top decile than other deciles by an order of magnitude. The per capita rebate diminishes this variation at the top of the distribution very marginally, though it does so at the expense of greater variation across the bottom half of the consumption distribution (see the right-most column of Table 7).

The progressive vertical redistribution across income groups is diminished if the lump-sum rebate is replaced with a proportional increase in the EITC and transfer benefits. As shown in Table 8, the poor benefit less under this hypothetical tax reform than under the revenue-neutral carbon tax and lump-sum rebate. Likewise, the wealthy are hurt less. Families in the third, fourth, and fifth consumption deciles benefit from the greatest magnitude of net tax cuts, $212 to $254, whereas the poorest families receive only a $109 tax reduction on average, a little more than one-third the size of the reduction they received under the lump-sum rebate. The richest families pay $1,090 more in tax on average, equal to a half percent of 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.

The more equal, yet still somewhat progressive, treatment of families across consumption deciles comes at the cost of greater heterogeneity of tax impacts within each consumption decile – as seen in Figure 2. Importantly, a plurality equal to 44% of the poorest families experience a tax *increase* under this hypothetical reform, even though the average impact is about a 1%

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[30] Since each family's extra tax burden is a decrease in annual consumption, then the standard deviation of the burden is the standard deviation of consumption within the decile. The coefficient of variation of consumption is defined as this standard deviation of consumption divided by the mean of consumption.

reduction in taxes as a percent of consumption. In the distribution of impacts within the first consumption decile, a long left tail of net tax cuts reduces the decile average reduction and conceals tax increases on these 44% of the poorest families. More than 25% of the poorest families enjoy a tax reduction equal to more than 2% of consumption. Families in the first eight consumption deciles enjoy tax reductions, on average, yet between 42% and 66% of families within each of these deciles experience tax increases of up to 2%. Though we see less heterogeneity in tax changes as a share of consumption among the richest families, the figure does show considerable variation in the levels of tax changes at the top of the distribution. The top consumption decile exhibits modestly more variation in tax treatment under the transfer expansion than under the lump-sum rebate. Across every consumption decile, the coefficient of variation of consumption is greater with the transfer expansion than with the lump sum rebate. This reform increases intra-class variation in consumption more so than does the carbon tax alone.

Finally, in Table 9, the carbon tax reform that recycles equal shares of revenues in the form of payroll tax reductions and increases in social security benefits most nearly approximates a proportional tax reform, while avoiding the most dramatic intra-class variation in tax changes. This reform 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, but they would be expected to 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 among the richest ten percent of families experiences a tax increase of $704, or 0.32% of consumption. The largest tax reduction is enjoyed by average families 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). Only among families in the highest consumption decile is the average net tax change positive. The average across 90% of families is a modest tax reduction.

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, 68% of the poorest families experience tax increases of zero to 2% of consumption, a share of the decile population that is greater than in any other decile. At the same time as most families incur very small tax increases, tens of thousands enjoy considerable tax reductions. Among the poorest families, 92,000 (0.5 percent) receive tax cuts equal to 5% of consumption or more. Reductions greater than ten percent of consumption are enjoyed by 27,000 (0.2 percent) families. Heterogeneity in tax changes as a percent of consumption declines across consumption deciles. None among the richest families receives a tax reduction greater than 5% or a tax increase greater than 3%. Consumption outcomes vary less within consumption deciles from this refunding mechanism than from any other considered here, but intra-class variation is still greater than if carbon tax revenues were not refunded except in the top decile. The coefficient of variation of consumption for the top consumption decile is lowest under the payroll tax and social security benefits reform than in any other scenario modeled in this paper, but only barely. Meanwhile, the coefficient of variation of consumption is greater for all other deciles by at least 50% and as much as 230% for the poorest families. .

Table 10 summarizes the coefficients of variation of consumption for each decile and each simulation. Though each of the three revenue-recycling mechanisms considered in this analysis achieves progressivity of the carbon tax reform, none mitigates across all deciles the intra-class variation in tax changes introduced by the carbon tax. The carbon tax without any revenue recycling minimizes variation in tax treatment across the poorest half of the consumption distribution. For all other deciles, the carbon tax without recycling produces the second-most homogeneous tax treatment of all simulations. The per capita rebate minimizes variation among the top half of the consumption distribution, 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 minimizes within-decile variation in outcomes 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.

6. Discussion

A number of studies have analyzed the implications of carbon taxes for vertical redistribution, explored the conditions under which a carbon tax is regressive, and explored complementary tax reforms that would be revenue neutral and preserve progressivity. But no previous research has explored the extent to which complementary tax reforms can achieve vertical parity and yet avoid variation in tax treatment among families of similar means. We consider three alternative mechanisms for revenue-neutral carbon tax reforms that utilize existing tax and transfer programs to mitigate regressivity and minimize disparities in outcomes within income classes. These outcomes under the three revenue-recycling simulations are compared to an alternative with no revenue recycling, though all simulations index transfer programs and income tax brackets in accordance with federal statute.

Cognizant that the four simulations evaluated in this paper hardly represent the breadth of potential tax reforms, the foregoing analysis lends important insights. First, and perhaps most importantly, the distributional analysis focused on vertical equity that comprises virtually all of the extant literature can yield misleading conclusions about the welfare changes of pluralities or even majorities of families, including the poorest. Because of large left tails in the distribution of tax changes as a percent of consumption, an aggregate decile statistic that indicates a tax cut for the average family conceals the fact that many or most families receive small tax increases. Our simulations show that this phenomenon holds not just for the lowest consumption deciles, but across consumption deciles for which the average tax change is estimated to be a 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 family-level analysis performed here is essential. Policymakers may want to know if a tax reform that delivers fairly large tax cuts to a minority of poor families also leaves most poor families worse off.

Second, while concerns about vertical redistribution can be ameliorated by recycling revenues in some fashion, we find that (1) a carbon tax with indexed transfers is not as regressive as conventionally measured, and (2) horizontal redistributions are *increased* for at least half of the population by any of the three revenue-recycling reforms we simulate. That is, consumption of energy-intensive goods exhibits greater commonality across families of similar means, when their means are measured by a proxy for permanent income than when measured by volatile annual cash income. Thus, among our simulations, a tradeoff arises between vertical and horizontal redistribution. The reform that rebates half of revenues in the form of 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 the revenue-recycling reforms, the per capita rebate minimizes disparities within income groups. 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.

Third, intra-class heterogeneity in tax changes tends to be greatest among families in the top consumption decile, that is, the richest ten percent of families. This finding surely reflects the limited capacity for means-tested revenue recycling and the relatively small rebates to offset considerably larger tax bills. It is also due, of course, to underlying heterogeneity in consumption patterns among the richest families. While the welfare of the poorest families enjoys 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 rich or poor families. Moreover, because of greater mean dollars of tax impacts among the rich families, high variability indicates large sums of money are changing hands. The standard deviation of tax change within the richest group is between $22,600-22,800 for these simulations. This narrow range across simulations indicates the ineffectiveness of these simulated reforms in addressing 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.

Finally, 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, their commute to work, or their 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 minimize 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. If owners of inefficient appliances received preferential rebates to compensate for their relatively high carbon taxes attributable to inefficient appliances, then their incentives to purchase efficient durables would fall. 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 electricity consumption, 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 their 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 (in order to retain a large rebate). Moreover, to the extent that rebates are based on characteristics of comparable families, then incentives to conserve along dimensions that define the 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 in hot climates to move to cool 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 the age, location, and 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 cooler climates. Such a one-time 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. Current policy may be inefficient if it insures holders of low-energy-efficiency 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 low-energy-intensity durables. Thus, the rationale for rebates pegged to consumption patterns may be weak, even if incentive problems can be resolved.

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TABLES AND FIGURES

Table 1: Carbon tax effects 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 percent
Natural Gas	$2.95/mcf	$1.29/mcf	44 percent
Coal	$35.16/ton	$46.86/ton	133 percent

[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

	Percent of total consumption, by consumption decile										
Consumption category	All Families	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	
	Tax Change as a percent of income	Tax Change as a percent of consumption	Tax Change as a percent of income	Tax Change as a percent of consumption	Tax Change as a percent of income	Tax Change as a percent of consumption	Tax Change as a percent of income	Tax Change as a percent 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 ithe carbon intensity of its inputs. Since total consumption is about $10 trillion, the $100 billion carbon tax is assumed to increase the general price level by about 1%. Certain government transfers and certain parameters in the individual income tax are indexed. As a result, the general price increase of 1% will increase government transfer expenditures by about $8 billion and decrease 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 percent consumption	Tax change as a percent 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 percent consumption	Tax change as a percent 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 percent consumption	Tax change as a percent 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 offsets and payroll tax reduction and Social Security benefits increase

Consumption Decile	Average change in tax burden	Tax change as a percent consumption	Tax change as a percent 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 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

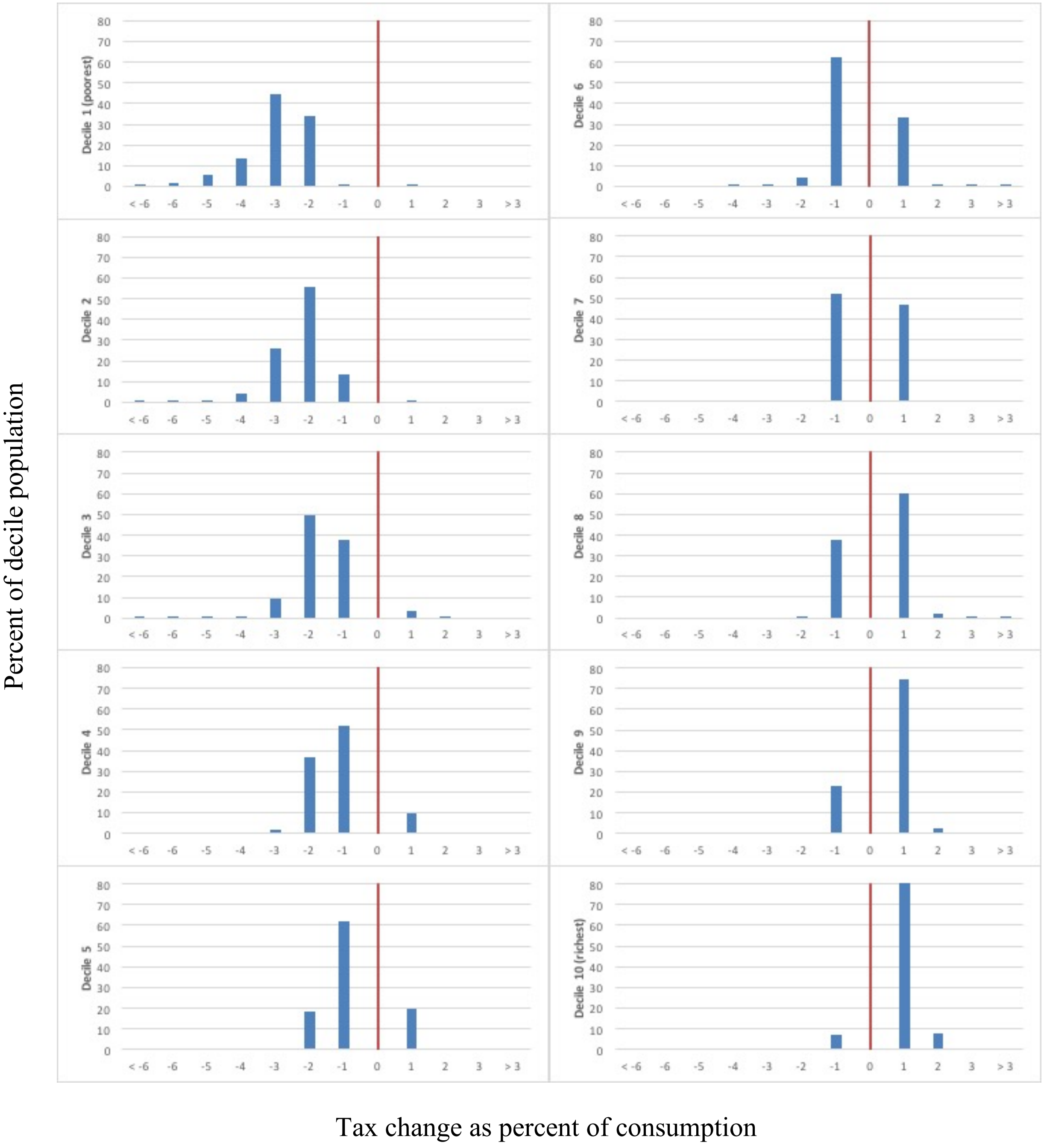

Figure 2: Distribution of Tax Changes for Carbon Tax with Proportional Increase in Transfers

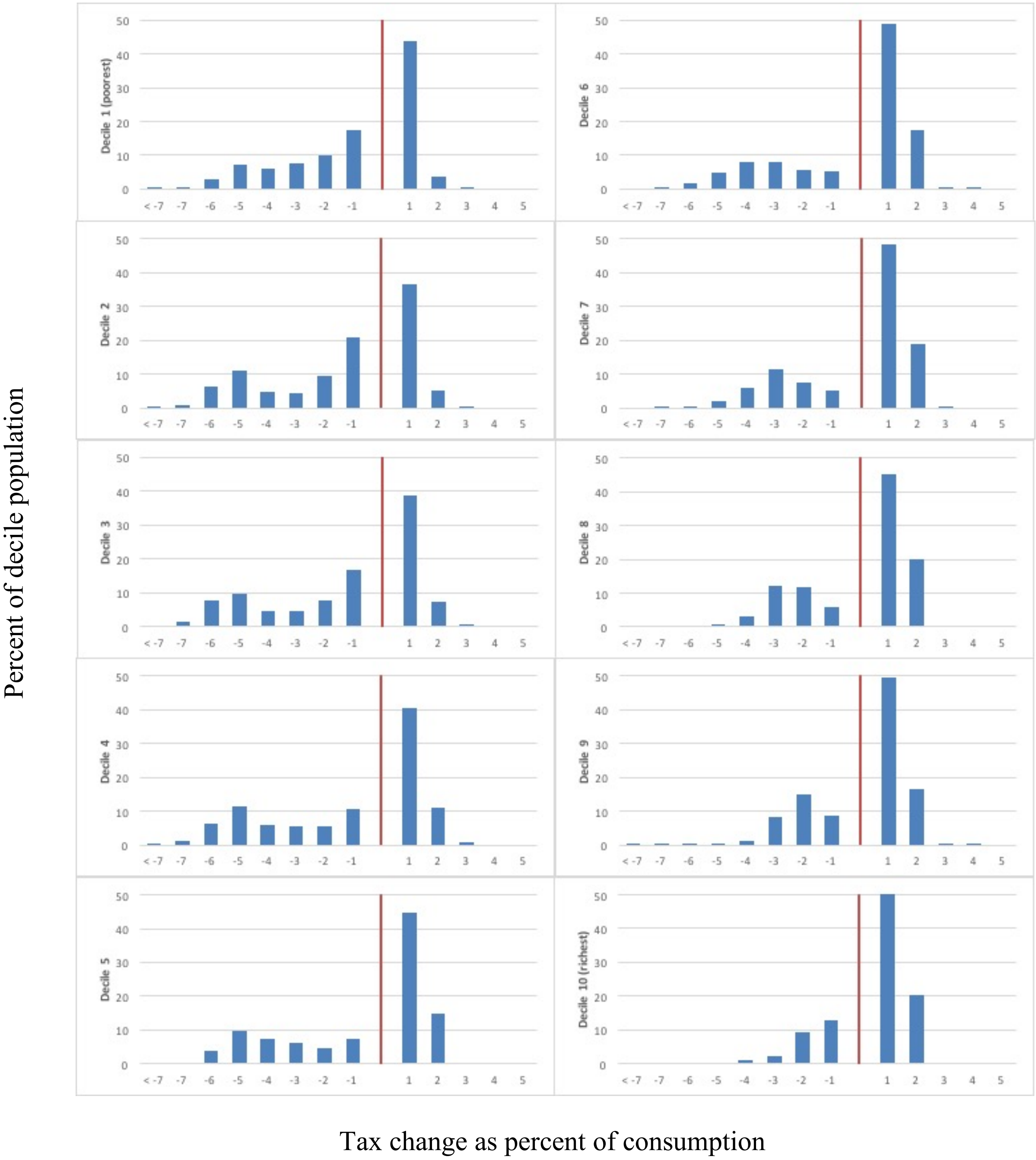

Figure 3: Distribution of Tax Changes for Carbon Tax with Payroll Tax Reduction and Social Security Benefits Increase