Vertical and Horizontal Redistributions from a Carbon Tax and Rebate

Julie Anne Cronin, Don Fullerton, Steven Sexton

Abstract: Are carbon taxes regressive? To calculate effects of a carbon tax on each family's expenditures, plus distributional effects of three revenue-recycling mechanisms, we employ the US Treasury Distribution Model. It includes 322,000 tax returns, matched social security information, imputations from the Consumer Expenditure Survey, and an input-output matrix to calculate output prices. Accounting for statutory indexing of federal transfer programs, the calculated carbon tax burden as a fraction of consumption is progressive. Rebate of revenues via transfers makes it even more progressive. Within each decile, we find large variation in energy demands such as for heat in winter and cooling in summer. As a result, commonly ignored horizontal redistributions within deciles are shown to exceed vertical redistributions between deciles. Rebates via transfers widen horizontal redistributions. Some reforms deliver net income gains to the poorest families on average, even as a majority of those poor families incur losses.

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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 (see Goulder and Parry 2008; Aldy et al. 2010; or the exception in Goulder et al. 2016). Despite potentially greater efficiency, however, carbon pricing has found little favor among US policy makers.

Julie Anne Cronin is at the US Treasury Department. Don Fullerton is at the University of Illinois and the National Bureau of Economic Research (dfullert@illinois.edu). Steven Sexton is at Duke University. For helpful suggestions, we thank Aparna Mathur, Janet McCubbin, Gilbert Metcalf, Adele Morris, Ian Parry, Dan Phaneuf, David Weisbach, anonymous referees, and participants at two NBER workshops. The Sloan Foundation and National Bureau of Economic Research provided financial support of the research conducted for this project by Don Fullerton and Steven Sexton, and the US Department of the Treasury provided use of tax return data by Treasury employees, including Julie Anne Cronin, to calculate summary statistics

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One concern is that 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 complementary changes to government taxes and transfers. In the United States, 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, 22) observed, "The 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. And 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.[1]

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shown in the paper. These confidential tax return data cannot be disclosed. Neither Fullerton nor Sexton had access to any individual tax return data. Views contained herein are ours and do not necessarily reflect the views or positions of the Sloan Foundation, the NBER, or the US Department of the Treasury.

[1] While we document the empirical variation of tax burdens and the further wide variation of transfer receipts, Sallee (2018) provides a useful theory showing the implausibility of achieving a Pareto improvement. Thus his paper and ours are complements, and a complete analysis could make use of both.

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. Policy makers 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.

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. Morris and Mathur (2015) consider reforms to address vertical distributions and regional disparities. 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 data set that provides the necessary information to evaluate the horizontal redistributions from income-targeted reforms. For a large sample of households, the US 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 US Treasury Distribution Model (TDM) has undertaken extensive imputations to construct a data set with the necessary heterogeneity across a large, representative sample of families with differing expenditures, sources of income, taxes paid, and transfers received.

This paper uses the US Treasury's merged file of 300,000 tax returns plus 22,000 nonfiler "information returns" that captures those whose income is below the tax-filing threshold.[3] Information returns permit the estimation of consumption for some of the poorest individuals in the country. 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

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[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 nonstandard income that the Treasury Distribution Model incorporates. See http://www.nber.org/~taxsim/.

[3] Treasury's Distribution Model uses only nondependent returns. The analysis below applies a weight to each return, where weights vary from 1 to 1,000. The resulting weighted data set represents 172 million US families.

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 burdens of a carbon tax are determined for these families by calculating carbon tax impacts on market prices for each consumption good and, then, computing the changes in family expenditures implied by price changes.[4]

Family burdens are calculated for each of four policy simulations that all include the same carbon tax, but three of which include alternative mechanisms of recycling net carbon tax revenues. Specifically, our carbon tax is combined with (1) no revenue recycling except for changes in transfers that are mandated by existing law to account for consumer price increases, (2) recycling of net carbon tax revenue via per capita rebate,[5] (3) revenue recycling via a 5.9% increase in the EITC and all existing transfers, and (4) equal shares of net revenue spent on a cut in the payroll tax and an increase in social security benefits. For each potential reform, we show distributional effects across and within deciles. To the extent that revenue-rebate mechanisms like those considered here prevent extreme or capricious burdens, policy makers 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.

This analysis is limited in various ways. First, our paper does not measure efficiency effects of a carbon tax, as these are extensively covered elsewhere with careful analysis of behavioral changes. Instead, we measure detailed distributional effects of a carbon tax reform, which can be addressed most simply by assuming no changes in behavior. Thus, each family's added burden is calculated as their observed expenditure on each consumption good times the price increase for that good.[6] A convenience of this ap-

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

[5] A lump-sum rebate was proposed by the Climate Leadership Council, which includes James A. Baker, Henry Paulson, George P. Shultz, Marty Feldstein, and Greg Mankiw. Their proposal reportedly would eliminate nearly all of the Obama administration's climate policies in exchange for a carbon tax that starts at $40 per ton and increases with time (though it would not change other energy policies). Revenue is returned in the form of a quarterly check from the Social Security Administration to "every American." We take that to mean a 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.

[6] Ideally, distributional effects could be measured by money-metric utility or the trapezoid loss in consumer surplus. But with no behavioral model, we focus on first-order effects rather than second-order effects of 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, including assumptions about how price responsiveness for various goods and services varies by income. Nonetheless,

proach is that none of our distributional results depends on the size of the carbon tax rate. Because quantities are fixed, doubling the tax rate would double the size of all absolute burdens with no change in relative burdens.

Second, we ignore changes in factor prices. Focus instead centers on household diversity in consumption of energy-intensive goods and in transfers received. Others study general equilibrium impacts on factor and output prices, but usually with a limited number of household groups. The 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.[7]

Third, 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.

Fourth, the merged data set 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 receipts. Nevertheless, the final section of this paper discusses redistribu-

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such behavioral responses can bear on the regressivity of carbon taxes, as in West and Williams (2004).

[7] We focus on long-run redistributions from differences in spending patterns and transfer receipts, as if looking at a post-adjustment equilibrium with a carbon tax (or cap-and-trade or other climate policy). In the short run, a new policy can substantially affect the market value of durable goods investments, like homes or automobiles, or it may affect unemployment and the value of industry-specific training. Moreover, rents from free permit allocations are reflected in firm profits and stock prices, benefiting shareholders who tend to be relatively well off (Parry 2004). Potential impacts of carbon pricing on the coal industry and Appalachian communities built around the coal industry have figured centrally in recent US elections, as have impacts on energy-intensive suburban communities (e.g., Glaeser and Kahn 2010; Stone 2015; Cass 2016; Ummel 2016). Even in the long run, a general equilibrium (GE) model could calculate changes in relative factor prices for labor and capital. Beck et al. (2015) review recent GE literature showing that the long-run wage/rental ratio could change in either direction, depending on assumptions and calibration of parameters like factor shares and substitution elasticities. A GE model with individual household data is difficult, though not impossible (Rausch et al. 2011), but such an effort here still would not definitively show whether the wage/rental ratio rises or falls. Note, however, that we do capture important effects on the sources side, namely, the increased transfer benefits from indexing, central to Beck et al. (2015).

tion and efficiency implications of family-specific compensation schemes based on these family characteristics.

Fifth, we do not account for the distribution of carbon policy benefits or of changes in other policies. Because carbon emissions are correlated with emissions of local pollutants that directly impact human health, a carbon tax may result in "cobenefit" reductions in local pollution emissions, yielding heterogeneous local benefits that depend on polluter responses and air transport. A consideration of these benefits is beyond the scope of this paper.

Finally, our analysis relies on benchmark measures of carbon intensity for consumption categories from 2007. Carbon intensities are likely to change with time, perhaps in response to policy, and these trends may further change family burdens from carbon taxes. The share of US electricity generated by natural gas plants has increased substantially in recent years, while the share of coal-fired generation declined. Thus electricity may become less carbon intensive, but the falling share of nuclear generation mitigates this effect. We cannot project future carbon intensities of all consumption goods, so our analysis is necessarily backward looking.

Notwithstanding these limitations, this analysis yields three key findings. First, despite the fact that electricity constitutes a high fraction of spending for poor families, we find that a US 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 proportional; (2) as shown below, our calculated family total carbon consumption is not clearly concentrated in high or low consumption deciles, which, with the first point, makes a carbon tax nearly proportional;[8] (3) transfers in the United States are indexed to correct for increases in consumer prices that accompany a carbon tax; and (4) transfers are a larger fraction of income for lower deciles.[9]

A second key finding is that the generally ignored horizontal redistributions are larger than the commonly studied vertical redistributions among the lower half of

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[8] In our data, the sum of direct and indirect carbon consumption is not a disproportionate share of low-decile total consumption, as is found in previous studies (e.g., Mathur and Morris 2014). One difference is that the TDM adjusts for imputed consumption, which is also part of our measure of income. Second, as described below, Treasury is able to preserve the accuracy of income information reported on tax returns when estimating consumption. Third, the TDM imputation from the CEX accounts for family size, which affects returns to scale in consumption and the family's relative well-being. Without this correction, a large share of spending on carbon-intensive goods could be due to a family's low income or to having few family members (and thus not benefiting from returns to scale).

[9] Others discuss these points separately and show how each can help make the carbon tax progressive. See, e.g., Fullerton et al. (2012), Beck et al. (2015), and Parry (2015), who also compares these effects for the United States and other countries. Our main contributions here are that we combine all four points simultaneously, use detailed calculations from the TDM, and provide the first calculations of horizontal effects from combined carbon tax and rebates.

the consumption distribution. 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% of consumption in the poorest decile to 0.80% of consumption in the richest decile. In contrast, heterogeneity of consumption within the first four deciles 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, across most deciles, 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 larger as a percentage 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 distributional studies of carbon taxes and discusses the policy interest in vertical and horizontal equity. Section 2 describes our data and methods used to simulate carbon taxes and rebates. Section 3 discusses measures of income and reports summary statistics. Section 4 describes simulations, while section 5 provides results. Section 6 explores further issues, while section 7 concludes.

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 United States and many European countries demonstrate that poor households devote greater shares of incomes to energy purchases than do others (Flues and Thomas 2015; Pizer and Sexton 2019). Yet, recent literature shows that such distributional concerns may be misplaced or at least exaggerated.[10] 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 life-cycle effects in earnings and savings (Poterba 1989; Bull et al. 1994; Hassett et al. 2009). According to the permanent income hypothesis of Friedman (1957), the

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[10] Energy taxes in developing countries can be progressive because the poor cannot afford air conditioners and cars (Sterner 2012; Pizer and Sexton 2019). Also, Parry et al. (2017) estimate that an increase in India's coal tax would be progressive. Many poor households are not connected to the grid, and so households among the lowest decile of consumption devote budget shares to electricity that are half those of the richest households.

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. For example, Metcalf (1999) and Dinan (2012) consider how to offset regressivity using existing tax code and transfer programs or lump-sum rebates. Metcalf (2009) develops a revenue-neutral tax reform package that raises \$90 billion from a \$15 tax per ton of carbon dioxide (CO_2) and returns the revenue through a tax credit of up to \$560 per worker. Mathur and Morris (2014) find that refunding merely 11% of revenues can fully compensate the poorest quintile of households—on average—for the added cost of a \$15 per ton tax on CO_2 emissions. However, such revenue recycling for the sake of equity comes at the cost of forgone 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 taxes.[11] 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 energy demands, income sources, and transfer program receipts. Pizer and Sexton (2019) observe that variation in energy consumption within income groups generally exceeds variation across income groups in the United States, Mexico, and United Kingdom. In the United States, some of the poorest 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, homeownership status, climate, electricity-generating infrastructure, home size and vintage, vehicle miles traveled, 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) find in a general equilibrium setting that variation in carbon tax burdens depends on the rebate of revenues. 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

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

group's benefit eligibility, take-up rates, and actual transfer receipts. Only 32% of families in our lowest decile receive EITC benefits.[12] 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 US families receive SNAP benefits, while 16% receive social security income.[13]

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.

The underpinnings of policy interest in vertical equity are much stronger than those of horizontal equity. As justification for vertical redistribution, philosophers since Bentham ([1802] 1978) have articulated the concept of diminishing marginal utility of income within the utilitarian social welfare framework. Less obvious, however, is the theoretic foundation for horizontal equity—the belief that equals should be treated equally. Musgrave (1959, 1990), for instance, contends that tax changes yielding better horizontal equity results are to be preferred to other changes for which vertical equity outcomes are comparable. A problem, of course, is how to define "equals." Those with the same income may pay different tax because of different behavior—such as marriage, homeownership, or consumption of carbon-intensive goods. If it is to mean equal in every respect, then their tax would indeed be the same (Kaplow 1989, 1992). Moreover, as Kaplow points out, pursuit of horizontal equity may give preference for common outcomes over those in which individual welfare levels are higher but heterogeneous.[14]

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[12] On EITC participation, see Eissa and Hoynes (2011). Benefit recipiency rates here are based on our US 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 (Bhargava and Manoli 2015). Estimates of unemployment insurance take-up range from 53% to 71% (Anderson and Meyer 1997).

[13] SNAP and social security benefits are included in the Treasury's cash income measure. Recipients will therefore be ranked higher than otherwise-similar nonrecipients. 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.

[14] Horizontal equity does appear in social welfare functions of Slesnick (1989) or Auerbach and Hassett (2002). For applications of these ideas to environmental policy, see Pizer and Sexton (2019) or Fischer and Pizer (2017).

We do not try to resolve the philosophical debate about horizontal equity. Instead, given that horizontal equity is an important consideration in policy debates, and that policy makers continue to grapple with how to "treat equals equally," 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 US Department of the Treasury has constructed a data set and model that we refer to as Treasury's Distribution Model (TDM). We use it to estimate impacts of a US carbon tax and of alternative rebate mechanisms. In this section, we describe the model in four main steps (summarized here and described further below).[15] 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 the prices of each of 389 consumption categories are estimated using a partial equilibrium, input-output model. Direct impacts are increases in energy prices due to the tax, whereas indirect effects reflect the increase in the prices of other goods and services as the cost of their energy inputs rises. And finally, these price changes are used to compute post-carbon-tax expenditures. Expenditures change only because of commodity price changes; quantities are assumed to be unchanged.[16]

Our use of tax returns mitigates measurement error in family income and consumption, and it affords reliable determinations of tax liability, both of which are important for our tax reform simulations.[17] Still, the data are imperfect, and various subcategories of income and consumption must be imputed, as explained in this section.

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[15] See Cronin (1999) for a complete description of Treasury's Distribution Model.

[16] Note two points here. First, each of the 389 consumption 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).

[17] Survey data may underreport income, and use of such data, without correction, can lead to implausibly high ratios of consumption to income (e.g., Toder et al. 2011). The majority of income reported on tax returns is reported by third parties and verified by the IRS (including wages, interest, capital gains, and social security income).

The accuracy of these imputations, however, is likely superior to other approaches because of the richness of Treasury data.

The TDM starts with a stratified random sample of 300,000 individual nondependent income tax returns drawn from among 143 million returns filed for 2010.[18] These returns are supplemented with tax records for 22,000 similarly sampled nonfilers using "information returns," including Forms W-2 filed by employers and various Forms 1099. Tax families are generated from these individual information returns based on filing status in previous years, age, targets for the nonfiling population from the Social Security Administration, and targets for nonfiling family structure based on the census. Together, these income tax and information returns are used to represent a population of 334 million people, or 172 million families, 28 million of whom do not file an individual income tax return.[19] The sample for 2010 is extrapolated to 2017 based on expected population size, national income, inflation, employment, and interest rates.

By employing individual tax returns and information returns for nonfilers, this approach benefits from reliable reporting. However, because some income is untaxed or unreported, a full measure of family welfare requires imputation of some income.[20] Imputed "cash income" includes such employer-provided fringe benefits as military service allowances, transportation and education benefits, as well as employer contri-

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[18] 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.

[19] 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 nonfilers from information returns for 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.

[20] Assignment of non-tax-based income items is subject to greater measurement error than the tax-based items but, to the extent possible, Treasury uses tax data to make informed imputations. For example, military allowances are only allocated to taxpayers who 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 (1999) for a description of income imputations in the TDM.

butions to health and life insurance policies.[21] 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 SNAP, WIC, TANF, and Low Income Home Energy Assistance Program (LIHEAP).[22] Saving or dissaving is imputed from the Survey of Consumer Finances (SCF).[23]

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 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% to top 10%). These distinctions yield 900 combinations or cells to which CEX records belong—and to which each tax family is assigned. Only CEX records from 2010–12 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 categories by assuming that the tax family has the same expenditure shares as the family in the matched CEX record. To these im-

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[21] A measure of "economic income" could include accrued but unrealized capital gains, income unreported on tax returns, and imputed net rent of owner-occupied housing. Those kinds of income are difficult to attribute accurately across families, however, and "economic income" is difficult for general users of Treasury's distribution tables to understand. Family economic income may be larger, but the rankings of families by cash income are similar.

[22] 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). For more detail, see Cronin (1999).

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

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

Commodity Prices	Price ($2017) Various Units[a]	Carbon Tax $25/mt CO2[b]	Percent Increase due to Carbon Tax[c]
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%

Note. mt = metric ton; bbl = barrel; mcf = thousand cubic feet.

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

[b] Based 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.

[c] Based on the assumption of 100% pass-through of the tax.

puted 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.

The carbon tax burden for each family is readily calculated, given their consumption expenditures and the calculated price changes for each of the 33 consumption goods. Treasury employs an input-output model to compute the price change for each consumption good according to the price changes of the intermediate inputs for each consumption category.[24] The carbon tax directly impacts the price of fuels, according to their carbon intensities. Using estimates of carbon intensity from the US Energy Information Administration and the Environmental Protection Agency, Treasury calculated that a $25 tax per metric ton of CO_2 would increase the price of coal by 133% (see table 1). Petroleum prices rise by 27%, and natural gas prices by 44%. These price increases are greater than those estimated in Metcalf (2007) and used by Hassett et al. (2009) for a $15 tax per metric ton of CO_2. Metcalf (2007) estimates that such a tax 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).[25]

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[24] For similar models, see, e.g., Fullerton (1996), Metcalf (1999, 2009), Hassett et al. (2009), and Mathur and Morris (2014). Treasury starts with a $25 tax per metric ton of carbon dioxide to calculate price changes (Horowitz et al. 2017). As described below, however, we scale Treasury's price calculations to a somewhat lower tax rate that yields a gross revenue of exactly $100 billion and that raises the price level by approximately 1%.

[25] 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.

These fuels are intermediate inputs to production of most other goods, so their estimated price increases induce increases in other product prices. To determine indirect price changes, the Treasury employs the most recent US Bureau of Economic Analysis benchmark input-output tables. These 2007 tables show how much of each output is produced by each of 389 industries and how much of each is used in production by each industry. 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.[26] This assumption results in output price increases across the 389 industries, which leads to another round of price hikes. Treasury iterates on this process, using the 389 industry input-output tables, until the price changes being observed are sufficiently small. Then, to obtain the final purchaser price of the good, they apply margins for transportation, retail, and wholesale trade.[27] The price changes for the 389 outputs are then mapped to changes in the 33 consumption goods defined in the CEX and imputed to the TDM.[28] Calculated price changes from the carbon tax are reported in the last column of table 2; earlier columns show corresponding price changes in previous studies. The table uses bold for the four carbon-intensive goods with the largest percentage price increases: electricity (9.0%), natural gas (14.8%), home heating oil (14.5%), and gasoline (14.8%). Other large price changes are for mass transit (4.6%) and air transport (5.5%). Most indirect price increases are less than 1% and are omitted (except for housing and health).

3. MEASURES OF INCOME AND SUMMARY STATISTICS

To measure redistributions across income groups, we need to choose a measure of "income" to rank families and divide them into deciles. The most common measure

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[26] In fact, Treasury splits oil and gas in the Benchmark I-O table, so they are actually using 390 industries. Also, as noted in our introduction, burdens could depend partly on changes in wage/rental ratios (e.g., Beck et al. 2015; or papers in Parry et al. 2015). Finally, we note that much of the power sector is still subject to price regulation, and the marginal fuels that determine prices can be different from baseload fuels.

[27] These margins are provided by the Bureau of Economic Analysis (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, $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.

[28] 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).

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	.70	.83	1.46
Food at work	.86	1.05	1.46
Tenant occupied dwelling	.31	.17	.88
Electricity	**12.55**	**5.21**	**9.01**
Natural gas	**12.28**	**18.92**	**14.83**
Water	.63	.46	2.45
Home heating oil	**9.56**	**6.10**	**14.51**
Health	.39	.32	.55
Gasoline	**7.73**	**4.72**	**14.81**
Mass transit	.90	.75	4.61
Air transportation	1.86	2.01	5.46
Other recreation services	.51	.31	1.14
Higher education	.30	.44	1.32

Note. Bold indicates the four carbon-intensive goods with the largest percentage price increases. mt = metric ton.

employed in 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. 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.[29] There-

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[29] Bull et al. (1994) observe in US CEX data that consumption closely follows income, exhibiting a “marked hump-shaped pattern” over lifetimes, rather than remaining relatively flat

fore, 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.[30] To the extent that the permanent income hypothesis is violated, and consumption does increase in the middle part of consumer lifetimes (e.g., Bull et al. 1994), then our low-consumption deciles may include young or old households whose lifetime consumption is understated. If carbon intensity of household consumption were strongly correlated with age, then our estimates of distributional impacts could be biased. For instance, if young and old families tend to have more carbon-intensive consumption than middle-aged families, then our estimates would overstate burdens in our low-consumption deciles (progressivity biased downward). In later tables, we consider the robustness of our results to life-cycle consumption by looking only at those who are 40–49 years old.

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. Therefore, we stratify families according to total annual consumption rather than annual income. (In fact, table 5 is the only table that classifies families by annual income, in order to compare implications of using annual income or annual consumption measures.)

For families classified into annual consumption deciles, the TDM's distribution of income and consumption at 2017 levels is reported in table 3.[31] In total, consumption is equal to 70% of income. The 10% of families with the highest annual consumption accrue 44.3% of total cash income and consume 36% of all goods and services. The

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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.

[30] 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).

[31] Cash income includes transfers for alimony, social security, unemployment compensation, and nontaxable transfers from the government, including the insurance value of Medicaid and Medicare and benefits from the following programs: SNAP, WIC, TANF, and Low Income Home Energy Assistance Program (LIHEAP).

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

Adjusted Family Consumption Decile	2017 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.

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.

For each consumption good listed in table 2, a row of table 4 shows each decile's expenditure on that good as a fraction of its total expenditure. 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 10% 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. 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 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 discernible 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 ex-

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 at 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 work	.0	.0	.0	.0	.0	.0	.1	.1	.0	.0	.0
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
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	**.9**	**.9**	**1.0**	**1.1**	**1.1**	**1.0**	**1.0**	**1.0**	**1.0**	**.9**	**.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	**.3**	**.2**	**.2**	**.2**	**.4**	**.4**	**.4**	**.3**	**.3**	**.3**	**.4**
Health	17.3	31.6	26.2	23.1	23.2	24.2	23.8	22.3	19.9	17.4	9.8
Gasoline	**5.5**	**4.0**	**5.0**	**5.8**	**5.7**	**5.5**	**5.4**	**5.8**	**6.0**	**5.6**	**5.4**
Mass transit	.5	.4	.3	.3	.3	.4	.5	.6	.5	.5	.5
Air transportation	.6	.4	.6	.2	.2	.3	.4	.5	.6	.7	.8
Other recreation services	.9	.3	.4	.5	.5	.6	.6	.8	.9	.9	1.2
Higher education	1.0	.4	.5	1.1	1.5	1.0	.7	.7	.5	.6	1.5

Note. Bold highlights the four goods that had the largest price increases in table 2.

penditure share for any reasonable aggregation of energy-intensive goods is roughly flat across consumption deciles.

4. CALCULATIONS FOR POLICY ALTERNATIVES

All simulations include an illustrative $100 billion carbon tax, either with no rebate or with one of three revenue-neutral types of rebate.[32] In all cases commodity prices rise relative to factor incomes to cover firms' extra costs of purchasing energy inputs and other energy-intensive intermediate inputs.[33] We assume that the government uses

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[32] Starting with Treasury estimates of all price changes for a $25 tax per metric ton of CO_2, we scale them to a $100 billion revenue total (consistent with Horowitz et al. 2017). The resulting tax is about $20 per metric ton of CO_2 and corresponds roughly to a 1% increase in price level, assuming no change in quantities consumed.

[33] Standard Treasury analyses such as in Horowitz et al. (2017) assume no changes in the price level, as is consistent with revenue-estimating assumptions. Instead, the tax is passed back to factor incomes, and relative output 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). That is, 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. As Horowitz et al. (2017) explain, however, progressivity of the carbon tax measured against annual income appears higher in their case with no price level increase than in our case, because our price level increase means family

some of the $100 billion revenue to index government transfer programs and tax parameters for those price increases.[34] Indexing of transfer programs requires government expenditures of $15.5 billion. Indexing of tax parameters lessens net revenues by $8.1 billion. This indexing is required to avoid inflation-induced "bracket creep" that would occur if taxpayers were pushed into higher tax rate brackets as nominal wages rise (but as purchasing power remains the same).

The remaining $76.4 billion in carbon tax revenues is an overall burden, or it is used 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 policy makers decide to offset the regressivity of the carbon tax by using the revenue to help low-income families cover the extra cost of goods 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,[35] (3) used to fund a proportional increase in all transfer program generosity,[36] 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 regres-

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burdens appear higher in years when annual income is low and consumption therefore exceeds income (e.g., by borrowing or dissaving). This distinction matters little in our paper, because we eschew annual income in favor of annual consumption to categorize families.

[34] 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 so that when product prices rise, transfer income is held harmless in real terms. Statutes require such indexing for SNAP, social security benefits, workers' compensation, and veterans' benefits. Other transfers are not indexed automatically, but we assume indexing of LIHEAP, TANF, and WIC. This additional indexing increases expenditures by $0.5 billion of a total $15.5 billion in expenditures for indexed transfers. 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.

[35] We consider a lump-sum rebate, as it is a common proposal (e.g., Climate Leadership Group, n. 4) and topic of researchers (e.g., Rausch et al. 2011). A reviewer points out, however, that a lump-sum rebate raises the total cost of a carbon tax relative to a policy that uses its revenue to fund reductions in distortionary taxes. The costs of a carbon tax can even exceed those of standards-based policies, because of greater effects on energy prices and a greater "tax interaction effect" (e.g., Goulder 1995, 2013; Goulder et al. 1999; Goulder and Williams 2003).

[36] Here, we increase existing transfer receipts by 5.9%, rather than expand eligibility to additional families. The maximum EITC in 2017 for a childless worker was $510, while the maximum for a worker with one qualifying child was $3,400. Mathur and Morris (2017) demonstrate that revenue from a tax of $32/ton CO_2 could hold the poor harmless and fund an expansion of the EITC to childless earners.

sivity, many discuss a refundable tax credit per person that functions as a lump-sum rebate (see n. 4). Because this tax credit is a rebate per capita, 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 toward 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 all cash transfers.[37] 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.[38] Payroll taxes decline 3.9%, and social security benefits increase 3.7%. This simulation is intended to mitigate both regressivity and within-decile heterogeneity in tax changes. 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 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 without recycling net revenues, which serves as a baseline against which to compare the three alternative rebate simulations. Distinguishing our analysis is the combination of (1) detail on 322,000 diverse families, (2) showing additional tax burden in each decile as a percentage of annual consumption, and (3) indexing of transfer payments and income tax brackets.[39] As shown in table 5, the latter two features both serve to diminish measured regressivity of the

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

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

[39] Dinan (2012) and Fullerton et al. (2012) account for inflation indexing of transfers but not of income tax bracket parameters. Brackets are indexed to price levels by statute—to avoid taxing more income at higher rates when prices and wages both rise. Thus, indexing results in lower revenues relative to a world in which taxes are not indexed.

Table 5. Comparing Carbon Tax Distributions Ranked by Income and Consumption Before and After Indexing Transfers and Tax Parameters

	Ranked by Adjusted Family Cash Income				Ranked by Adjusted Family Consumption			
	Before Indexing		After Indexing		Before Indexing		After Indexing	
Decile	Tax Change as % of Income (1)	Tax Change as % of Consumption (2)	Tax Change as % of Income (3)	Tax Change as % of Consumption (4)	Tax Change as % of Income (5)	Tax Change as % of Consumption (6)	Tax Change as % of Income (7)	Tax Change as % of Consumption (8)
1	1.21	.86	.71	.50	1.08	.89	.54	.45
2	.99	.97	.54	.52	1.03	.96	.58	.54
3	.94	.99	.49	.52	.95	1.01	.55	.58
4	.89	.99	.50	.55	.89	1.00	.54	.61
5	.83	.97	.52	.61	.82	.97	.55	.65
6	.78	.96	.56	.69	.76	.96	.56	.71
7	.76	.97	.58	.74	.74	.98	.57	.75
8	.73	.99	.57	.78	.72	1.00	.55	.76
9	.66	.97	.52	.78	.65	.96	.50	.74
10	.52	.94	.45	.81	.53	.94	.46	.80
Total	.67	.96	.51	.73	.67	.96	.51	.73

Note. The carbon tax is scaled to hit $100 billion without indexing. 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 $15.5 billion and decreases individual income tax receipts by about $8.1 billion. Together, all else equal, these two provisions would be expected to decrease carbon tax revenue by roughly $23.5 billion.

carbon tax. Even with no revenue-recycling mechanism, they jointly convert the carbon tax from regressive to progressive.

The first column of table 5 shows annual incidence of a carbon tax without indexing, with families ranked by annual income, and with tax burden shown as a percentage of annual income. This incidence appears very regressive: the carbon tax is 1.21% of income for the bottom income decile but only 0.52% of income for the top income decile.[40] The third column accounts for the indexing provisions but still ranks by annual income and still measures the added burden as a percentage of income. Then measured regressivity diminishes: 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, in the fourth column, the carbon tax with indexing is progressive, even when families are still ranked by income: the carbon tax is 0.50% of consumption for the lowest annual income decile and 0.81% for the top annual income decile.

In the right half of table 5, the same families are instead ranked by annual consumption. When column 8 takes each burden as a percentage of consumption and accounts for indexing, the carbon tax is slightly more progressive: the burden rises almost monotonically from 0.45% of consumption for the lowest consumption decile to 0.80% of consumption for the highest decile.[41]

All other tables use this ratio of net burden to consumption, so column 8 from table 5 is repeated in table 6, as column 2, along with other results for our first case, the carbon tax with indexing but no rebate. The first column of table 6 shows that the average family in the first decile has an added tax burden of $51, while the average family in the richest decile has $1,757 of extra tax.[42] Then the third column shows the standard deviation (SD) of the tax change, and the fourth column shows this

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[40] As is standard in Treasury distribution tables, rankings by cash income and consumption have been adjusted by equivalence scales to account for both the number of persons in the family and returns to scale in sharing resources. Each family's income or consumption is divided by the square root of the number of persons in the family, to approximate the true level of well-being for 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 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.

[41] "Progressive" is defined by a ratio of burden to income that rises with income (annual consumption is our proxy for permanent income). This ratio in column 8 falls slightly from decile 8 to 9, but otherwise rises monotonically from each decile to the next. However, this ratio may fall with income from one family to the next within a decile.

[42] A different question is the cost of protecting each decile from any burden. Our results are weighted to represent all 172 million US families, so each decile contains 17.2 million. In the lowest decile, for example, the average burden is $51 (after indexing), so full compensation to them could conceivably cost only $877 million ($51 × 17.2 million).

Table 6. Incidence by Decile of Carbon Tax with Indexing and No Rebates

Consumption Decile	Average Change in Tax Burden (1)	Tax Change as % of Consumption (2)	Standard Deviation of Burden (3)	Coefficient of Variation of Consumption (in %) (4)	Families with a Tax Decrease (in %) (5)
1	$51	.45	$64	.56	13.6
2	$95	.54	$103	.59	15.4
3	$134	.58	$152	.66	14.9
4	$178	.61	$195	.66	13.9
5	$245	.65	$213	.57	12.0
6	$330	.71	$250	.54	7.9
7	$434	.75	$342	.59	4.9
8	$544	.76	$360	.51	3.0
9	$674	.74	$422	.47	2.0
10	$1,757	.80	$22,725	10.37	.8

SD as a percentage of mean family consumption. Each family's extra burden reduces its annual consumption, so the SD of the burden is the SD of consumption within the decile. Therefore, in the fourth column, the coefficient of variation (CV) of consumption is this SD of the tax change divided by mean consumption.

The SD increases from $64 for the first decile to $422 for the ninth decile. Between these deciles, mean consumption in the denominator of the CV rises faster than SD in its numerator, so the CV falls from 0.56% to 0.47% from the first to the ninth decile (though not monotonically). For the top decile, however, both the SD and CV increase dramatically (to $22,725, or 10.37% of consumption). This variation within the top decile is difficult to interpret, because the top decile is very heterogeneous and family income or consumption is 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.[43] The added variation within this top decile can

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[43] 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, other studies using tax data have separated the top 1% of income from the rest of this top decile. We do not focus on the top 1% or bottom 1% (except for one policy scenario in table 8 below). We have good tax data for the top 1%, but Treasury imputes data for nonfilers in the bottom 1%. Also, we have to match each of

Table 7. Incidence by Decile of Carbon Tax with Indexing and Per Capita Rebate

Consumption Decile	Average Change in Tax Burden (1)	Tax Change as % of Consumption (2)	Standard Deviation of Burden (3)	Coefficient of Variation of Consumption (in %) (4)	Families with a Tax Decrease (in %) (5)
1	−$294	−2.59	$203	1.79	100.0
2	−$325	−1.86	$236	1.35	99.7
3	−$297	−1.29	$262	1.14	96.6
4	−$258	−.88	$281	.96	90.1
5	−$206	−.55	$252	.67	80.2
6	−$125	−.27	$237	.51	66.8
7	−$33	−.06	$276	.48	52.4
8	$71	.10	$280	.39	37.8
9	$204	.23	$347	.38	23.1
10	$1,270	.58	$22,718	10.37	7.2

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.

Finally, in table 6, the last column (col. 5) shows the percentage of families with a negative net burden ("percent winners"). This addition of a carbon tax with no rebate might be expected to create only positive burdens, but indexing provisions effectively raise all families' transfers—including social security—by a single price index with one set of weights for all consumption goods. Therefore, any family with little or no need for air conditioning or heat may actually have little extra carbon tax burden but receive a net gain from increased transfers that reflect the nationwide average increase in costs of consumption goods. Transfer income as a fraction of total consumption falls monotonically from the first to the tenth decile. Percent winners falls monotonically from 15.4% at the second decile to 0.8% at the tenth decile. Among the first decile, 13.6% of families experience a decrease in tax burdens.

When carbon tax revenues are refunded in a per capita lump-sum payment, as shown in table 7, the net additional burden as a percentage 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. The average reduction in tax burden for the

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the 322,000 tax families to one of the 4,900 CEX families, where the CEX has few if any observations in the top or bottom 1% of income. Moreover, existing literature about the top or bottom 1% have focused on extreme inequality itself, and particularly on changes to income of the top 1% over recent decades, whereas our interest is on overall vertical and horizontal redistributions from a carbon tax.

poorest 10% of families is $294, or 2.59% of consumption. The richest families experience a net tax burden increase of $1,270 per year, equal to 0.58% of their consumption.

However, not all of the poorest 10% of families enjoy net tax reductions under this lump-sum rebate. The full distribution of tax changes as a percentage of consumption within select deciles is presented in figure 1*a*. This figure includes a gray vertical line to denote the boundary between winners and losers, and it plots the distribution of outcomes for five deciles: the first, second, fifth, ninth, and tenth. For each decile, we calculate the share of its population experiencing a tax change as percentage of consumption in each 1% range (such as zero up to 1% more tax, or those between 1% and 2% more tax). The figure plots those shares for nine discrete bins, from a net tax cut of greater than 6% to a net tax increase greater than 3%.

The figure shows that 7% of the poorest families receive net tax cuts of more than 4% of consumption, while 0.01% bear more burden. In the highest decile, the figure shows less heterogeneity in tax changes as a percentage of consumption among families. 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 third column of table 7 reports the standard deviation of the tax change within each decile. This SD increases from $203 for the lowest decile to $347 for the ninth decile, while the CV falls monotonically from 1.79% for the poorest decile to 0.38% for the ninth decile. The SD 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 fourth deciles. But the CV 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 percentage of consumption in low consumption deciles. An alternative to per capita rebates could be the same rebate per family, 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 as shown 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 mostly greater than in table 6 for the carbon tax alone.[44] But the increase in EITC and all transfers is not as progressive as the per capita rebate in table 7. Although transfers are important sources of income in lower

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[44] The net gain as a percentage of consumption rises from decile 1 to 2, because the first decile has more single person families that receive smaller transfers and are less likely to be eligible.

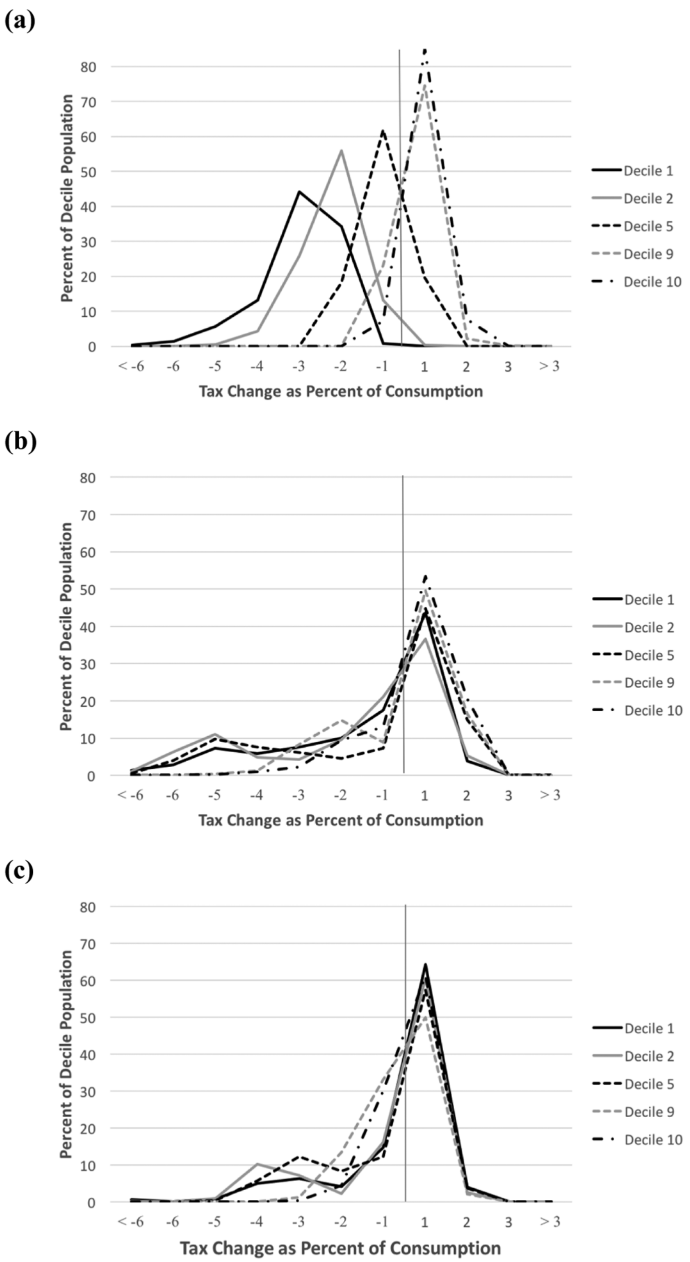

Figure 1. Distribution of net tax changes by decile for each rebate policy. *a,* Carbon tax with per capita rebate (CT2). *b,* Carbon tax with proportional increase in transfers (CT3). *c,* Carbon tax with payroll tax cut and social security benefits increase (CT4). For each of three carbon tax

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

Consumption Decile[a]	Average Change in Tax Burden (1)	Tax Change as % of Consumption (2)	Standard Deviation of Burden (3)	Coefficient of Variation of Consumption (in %) (4)	Families with a Tax Decrease (in %) (5)
1	–$109	–.96	$233	2.05	53.0
2	–$187	–1.07	$339	1.93	58.5
3	–$224	–.97	$469	2.04	53.5
4	–$254	–.87	$613	2.09	47.7
5	–$212	–.56	$736	1.96	40.0
6	–$108	–.23	$813	1.74	33.7
7	–$31	–.05	$913	1.59	32.6
8	–$5	–.01	$1,022	1.46	34.2
9	$59	.06	$1,155	1.26	33.8
10	$1,090	.50	$22,773	10.39	26.1

[a] The bottom 1% experience an average net tax change of –$104, or –0.97% of consumption. The standard deviation is $255, and the coefficient of variation of consumption is 2.38%. For the top 1%, the average net tax change is $6,211, or 0.73% of consumption. The standard deviation is $71,661, and the coefficient of variation of consumption is 8.42%.

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.

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 percentage of consumption greater than 1%, with the exception of the second decile where the average tax cut is 1.07% of consumption.

Figure 1*b* shows that this relatively more equal treatment of families across deciles comes at the cost of greater heterogeneity of tax impacts within each decile. Looking at impacts within the poorest decile, 47% of families experience a tax increase, even

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rebate policy simulations, the figure reports the inter-decile distribution of net tax changes as a percentage of consumption for select consumption deciles (first, second, fifth, ninth, and tenth). For each discrete bin of net tax change percentage on the horizontal axis, it depicts on the vertical axis the percentage of the decile population calculated to experience a net tax change in that bin.

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 deciles enjoys a net tax cut, yet figure 1*b* and table 8 show that 42% to 66% of families within each of these deciles experience tax increases (sometimes over 2% of consumption). Comparing figure 1*a* and 1*b* indicates that each selected 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.[45]

For our final reform, table 9 shows the carbon tax when revenue is recycled in equal shares to payroll tax reductions and increases in social security benefits. This package is slightly progressive from deciles 4 to 10, but not from deciles 1 to 4. Still, it yields a small net tax cut for the first nine deciles and a tax increase only for the richest decile. The poorest 10% 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 deciles, each of which receives a tax cut equal to $113 (or 0.38% and 0.30% of consumption, respectively).

Compared to the other reforms, 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 transfers. As a result, gains to the poor are more limited than in the other proposed reforms, while the losses to the rich are also more limited.

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[45] Our paper is not about extreme inequality or about recent changes to the income share of the top percentile, but our note to table 8 shows some effects of this policy scenario on the top and bottom 1% of the consumption distribution. Effects for the bottom 1% are similar to those of the bottom 10%, probably because the Treasury had to impute much information for the lowest-income nonfilers by using CEX and transfer program information from other families in the first decile. Likewise, the distribution of tax changes for the top 1% is similar to those of the top decile. These numbers have insufficient accuracy, which is why we have not emphasized them.

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

Consumption Decile	Average Change in Tax Burden (1)	Tax Change as % of Consumption (2)	Standard Deviation of Burden (3)	Coefficient of Variation of Consumption (in %) (4)	Families with a Tax Decrease (in %) (5)
1	–$18	–.16	$153	1.33	31.6
2	–$44	–.25	$228	1.29	36.9
3	–$74	–.32	$309	1.33	37.6
4	–$113	–.38	$388	1.32	40.6
5	–$113	–.30	$437	1.15	38.8
6	–$89	–.19	$471	1.01	37.7
7	–$70	–.12	$543	.94	40.1
8	–$81	–.11	$593	.83	43.0
9	–$86	–.09	$664	.73	47.8
10	$704	.32	$22,616	10.31	34.9

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. But further analysis of heterogeneous tax treatment within each decile reveals the opposite. The last column in table 9 shows that a majority of families in all deciles experience tax increases (though fig. 1*c* shows for select deciles that most of these extra taxes are only up to 1%). In fact, tax increases apply to 68% of the poorest families, a share that is greater than for any other decile.

For the 17.2 million families in the poorest decile, 92,000 (0.5%) receive tax cuts or benefit increases equal to 5% of consumption or more. Gains greater than 10% of consumption are enjoyed by 27,000 families. Heterogeneity in tax changes as a percentage of consumption declines across most deciles in table 9 or figure 1*c*. None of 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).[46] Meanwhile, the CV of consumption is larger than in the case with no refund for the first nine deciles, and it is twice as large for the first five deciles.

The distributional impacts of all these reforms are summarized in figure 2. For each reform, a whisker bar is used to depict the range from the 10th to 90th percentile of the distribution of tax changes within each decile, and an *x* is used to show the median tax change as a percentage of consumption. It is evident in the figure that the

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[46] 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.

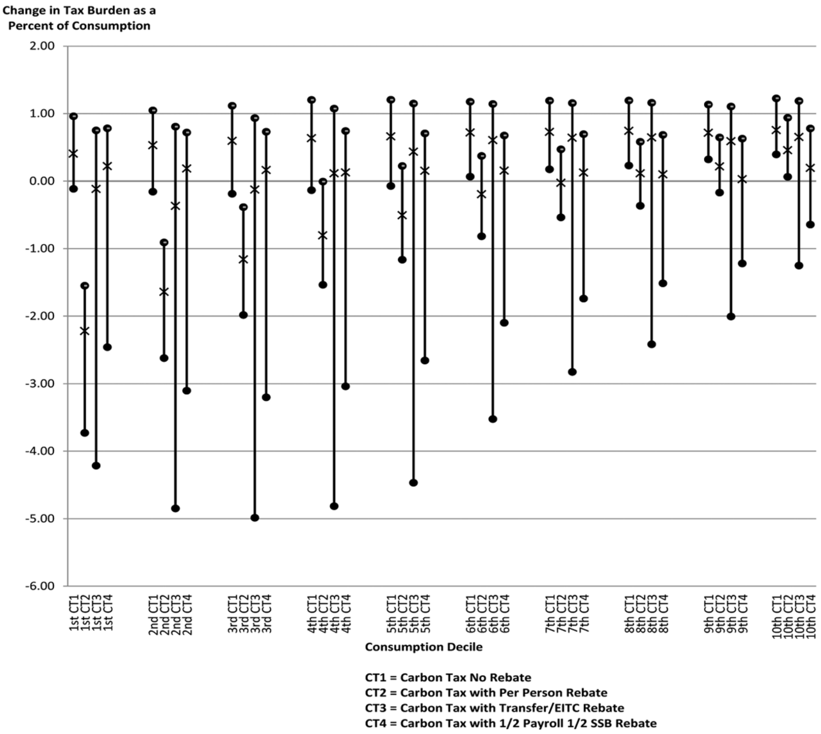

Figure 2. Distribution of the change in tax burdens as a % of consumption by decile, for a carbon tax with and without rebates (range of each bar is 10th to 90th percentile)

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 percentage 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 2 is that the richest decile has the shortest whisker bars of any decile, that is, the least variation between the 10th and 90th percentile of the gain or loss as a percentage of consumption within the decile. Yet its standard deviation as a percentage of consumption is far higher than any other decile (the CV, for all four reforms). The reason is that the richest 10% within this richest decile have significantly more consumption and therefore more change in burden than others within the middle 80% of the decile.

While prior literature 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 SD of total tax 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 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 preexisting total tax burden. Still, some might hold that avoidance of capricious gains and losses is a worthy objective of climate policy.

6. FURTHER EXPLORATIONS

In order to address the sensitivity of our results to use of consumption as a proxy for permanent income, we evaluate distributional effects for only those families whose primary filer is aged 40–49 (both for the carbon tax alone in table 10 and for the case with EITC and transfer expansion in table 11). The idea is to control for the life cycle of consumption by considering families at a similar stage of the life cycle but among whom consumption may still differ. For ease of comparison, each table first reports effects for all families (from prior tables) and then for only those with filers aged 40–49. Qualitatively, results for both reforms are unchanged by looking at only this age group. Comparing column 2 to column 1 in both tables demonstrates that the magnitudes of mean tax changes as percentage of consumption are raised by considering only 40–49-year-olds, but the pattern of vertical distribution is similar. The tax change as percentage of consumption still increases nearly monotonically from the lowest to highest decile, with or without conditioning on age. Comparing columns 4 to columns 3 in both tables shows that variation within deciles is lower for those aged 40–49 than for all families, but again the pattern is similar: for those middle-aged, just like all families, the CVs for the carbon tax with rebates through transfers are all larger than for the carbon tax alone (especially for the first five deciles). Also, the percentage of families that enjoy tax decreases is shown in column 6 for those aged 40–49. Again, these results for both reforms are similar to those for all families in column 5: the percentage who are winners rises from decile 1 to 2 and then falls almost monotonically.

Overall, even if the patterns are similar, these results indicate that mid-life-cycle families are less likely to gain from the tax changes, and they experience larger tax

Table 10. Incidence by Decile of a Carbon Tax with Indexing and No Rebates, for All Families and for Those with Primary Filer Aged 40–49

Consumption Decile	Tax Change as % of Consumption (1)	Tax Change as % of Consumption Ages 40–49 (2)	Coefficient of Variation of Consumption (in %) (3)	Coefficient of Variation of Consumption (in %) Ages 40–49 (4)	Families with a Tax Decrease (in %) (5)	Families with a Tax Decrease (in %) Ages 40–49 (6)
1	.45	.65	.56	.55	12.2	5.0
2	.54	.67	.59	.58	14.3	7.4
3	.58	.74	.66	.65	14.1	4.0
4	.61	.81	.66	.46	13.4	1.5
5	.65	.86	.57	.50	11.7	.7
6	.71	.86	.54	.48	7.6	.7
7	.75	.88	.59	.45	4.7	.3
8	.76	.88	.51	.39	2.8	.3
9	.74	.88	.47	.36	1.9	.1
10	.80	.85	10.37	5.20	.8	.4

Table 11. Incidence by Decile of a Carbon Tax with Indexing and Proportional Increase in EITC and Transfers, for All Families and Those with Primary Filer Aged 40–49

Consumption Decile	Tax Change as % of Consumption (1)	Tax Change as % of Consumption Ages 40–49 (2)	Coefficient of Variation of Consumption (in %) (3)	Coefficient of Variation of Consumption (in %) Ages 40–49 (4)	Families with a Tax Decrease (in %) (5)	Families with a Tax Decrease (in %) Ages 40–49 (6)
1	−.96	−.62	2.05	1.70	51.4	48.7
2	−1.07	−.64	1.93	1.59	57.5	54.1
3	−.97	−.33	2.04	1.55	52.7	43.8
4	−.87	.06	2.09	1.37	47.2	29.2
5	−.56	.47	1.96	1.10	39.8	15.4
6	−.23	.62	1.74	.95	33.6	9.8
7	−.05	.74	1.59	.72	32.5	6.1
8	−.01	.73	1.46	.74	34.2	6.2
9	.06	.76	1.26	.68	33.8	5.2
10	.50	.79	10.39	5.22	26.0	3.6

changes. This result may reflect this age group's higher consumption and lower transfer receipts. But results also suggest that the vertical redistribution we observe in the main analysis is not likely to be biased by our use of consumption as a proxy for permanent income.

We now turn to explore our result that horizontal redistributions within deciles are larger than redistributions between deciles—even for the carbon tax alone and especially with rebate of revenue via transfers. Table 12 helps explain this result. The top panel shows the SD within each decile for spending on each energy good as a per-

Table 12. Variation in Energy Expenditure by Type, and Transfer Receipts by Type

Consumption Decile	SD within Each Decile of Spending or Receipts as % of Mean Family Consumption				
	Energy Expenditures				
	Heating Oil	Natural Gas	Electricity	Gasoline	Total
1	1.2	1.9	3.9	4.3	7.38
2	1.0	1.8	3.7	5.2	7.99
3	1.3	1.9	3.3	5.2	7.64
4	1.6	1.9	2.9	4.8	6.90
5	1.6	1.7	2.5	4.4	6.31
6	1.6	1.5	2.4	4.3	6.06
7	1.5	1.5	2.3	4.8	6.45
8	1.7	1.5	2.3	4.3	6.18
9	1.4	1.2	2.3	3.9	5.59
10	7.7	9.7	43.2	59.1	107.18
	Transfer Receipts				
	EITC	Social Security	SSI	SNAP	Total
1	9.18	26.76	8.14	11.62	30.09
2	10.93	26.38	8.74	9.65	28.07
3	7.78	27.22	7.99	8.06	28.60
4	4.81	27.12	7.01	6.26	28.72
5	2.86	24.64	5.68	4.37	26.80
6	1.37	21.60	4.28	3.00	23.61
7	.47	19.44	3.38	1.87	20.88
8	.17	17.87	2.76	1.35	19.07
9	.07	15.76	2.26	.51	17.09
10	.01	7.48	.79	.07	8.97

Note. The "total" column is not the sum of entries in that row. Rather, it uses each family's total energy spending to calculate the SD within the decile as a fraction of mean family total consumption spending.

centage of mean family consumption (SD/cons).[47] This statistic for each fuel is over 1% of consumption in every decile. The first nine deciles do not differ much from each other, but the tenth decile has a larger SD/cons (because consumption itself is unbounded in this decile). Electricity differs from other fuels in that the SD/cons declines monotonically from the first decile to the ninth, because home cooling and use of appliances vary more in lower deciles. The lowest decile's highly variable energy spending helps explain its high variability of carbon tax burden. Gasoline contributes most among fuels to total intra-decile variation, likely reflecting heterogeneity in personal vehicle travel and commuting distances.

The lower panel of table 12 shows SDs of select transfer receipts and of total transfer receipts, each as a percentage of consumption. The greatest variation in receipts of existing transfer programs is due to these selected transfers (EITC, Social Security, SSI, and SNAP). Social security income varies considerably more than receipts of other transfers, because only some in every decile are retired. Even the variability of total transfer receipts is only marginally larger than the variability of social security receipts. Thus, carbon tax rebates that expand social security benefits will increase variation in horizontal distributions. The SD/cons for transfer receipts are substantially larger than for energy expenditures (except in the top decile). Because this heterogeneity in transfer receipts declines from poor to rich, any rebate that expands transfer programs will induce greater variation in tax changes among the poor. EITC variation within the first three deciles is large (see n. 35). Since it exceeds variation of total energy spending, the oft-proposed rebating of carbon tax revenues via enhanced EITC benefits is likely to increase heterogeneity in horizontal distributions among the poor more than does the carbon tax itself.

7. CONCLUSION

The four simulations evaluated here hardly represent the breadth of potential tax reforms, but our analysis nonetheless provides important insights. First, contrary to the common belief that a carbon tax in the United States is regressive, we show that it is progressive—even without rebate of revenue—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, we find that a distributional analysis focused on vertical burdens can yield misleading conclusions about welfare changes for majorities of families, including the poorest. Because the usual rebate mechanisms can provide large gains as a percentage of consumption for some poor families, an aggregate decile statistic that reports a tax

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[47] The last column is not the sum of the row, but the SD for total fuel spending over total consumption. This number exceeds the square root of the sum of squared fuel-specific SDs, implying that fuel expenditures are not independent across categories and that expenditures are positively correlated across two or more of the categories.

cut for the average family conceals the fact that many or most of them receive tax increases. Our simulations show that this phenomenon holds not just for the lowest deciles, but across many deciles. Thus, the micro-level analysis performed here is essential for policy makers to be able to know if a tax reform that delivers an overall tax cut to poor families also leaves most of them worse off.

Third, while the carbon tax alone creates disparity of net tax changes within each decile, any of our three revenue-recycling mechanisms increase these horizontal disparities for at least half of the population. 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 widens the horizontal disparities relative to the carbon tax alone (for all but the richest decile). 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 Treasury's Distribution Model affords high-fidelity assessments of rebate mechanisms that utilize income channels, the data preclude study of rebate mechanisms based on family characteristics that could better reduce disparities among families of similar means. In particular, we do not know the age or insulation of a family's dwelling nor the energy efficiency of its appliances and vehicles. We do not observe each family's weather, commuting distance, or built environment (e.g., commuter rail or electricity grid). These characteristics affect household carbon emissions and, were they known to us, could be used to design household-specific rebates to offset carbon tax burdens. While carbon tax rebates based upon these characteristics could reduce intra-class variation in net burden outcomes, they would also affect efficiency by reducing the price signal induced by the carbon tax—at least along some margins. For example, compensating owners of energy-inefficient furnaces or cars for high carbon taxes diminishes their incentives to buy efficient durables. Likewise, compensation for extra burdens in areas with extreme climates could reduce the incentive to weatherproof or to move. Still, the efficiency cost of such transfers may be quite low, if they were targeted only to low-income families.

To avoid these incentive problems, possibly, 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. If it were a surprise, and not continued, this one-time transfer might not affect incentives for future conservation, energy efficiency investments, and purchases of smaller homes in more temperate climates. Such a payment would be extremely difficult to implement in practice, however, and many may believe that heavy energy users "ought" to pay for it.

Finally, given its reliance upon Treasury's Distribution Model, this analysis is inevitably focused on distributional impacts of a US carbon tax. Worldwide, as 100 parties to the Paris Agreement implement carbon pricing instruments to reduce emissions and achieve their Intended Nationally Determined Contributions, the prospects of imminent carbon pricing in the United States are dim. Elsewhere, 40 countries and 20 subnational governments already price carbon (World Bank 2016). The results of this analysis are relevant to planners elsewhere who are concerned about vertical and horizontal redistributions from a carbon tax, and they are most relevant to planners in developed countries where the poor have access both to energy and to government transfers. We show that heterogeneity can complicate efforts to return carbon tax revenues via existing transfers in ways that do not increase disparity of tax changes within an income group.

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