The Impact of a Carbon Tax on Inequality in the United States

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Anders Fremstad[1] and Mark Paul[2]

Abstract

Climate change and economic inequality are inextricably linked. Despite widespread agreement among economists that a carbon tax is the most efficient mechanism to curb greenhouse gas emissions, such a tax exacerbates inequality since low-income households spend a greater share of their income on carbon-intensive goods. Using Input-Output tables, we calculate the carbon intensity of goods to estimate households' carbon footprints and examine how a tax of $50 per ton of CO_2 impacts multiple forms of inequality. Devoting carbon tax revenue to provide all people with an equal carbon dividend makes the policy progress, minimizes redistribution among households of similar means, mitigates group-based inequalities, and increases welfare for 55 percent of individuals, including 84 percent in the bottom half of the distribution. While some economists have dismissed dividends on efficiency grounds, we show that macroeconomic benefits of tax cuts are insufficient to protect the purchasing power of a majority of Americans.

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[1] Anders Fremstad, Department of Economics, Colorado State University, C306 Clark Building, Fort Collins, CO. (413) 820-8281 anders.fremstad@coloradostate.edu
[2] Mark Paul, Samuel DuBois Cook Center for Social Equity, Duke University, Campus Box 104407, Erwin Mill Building, Durham, NC. (413) 230-9175 mark.paul@duke.edu

1. Introduction

Climate change and economic inequality are inextricably linked. Without substantial action to reduce greenhouse gas emissions, research finds that climate change will disproportionately harm the poor both within the United States (Hsiang et al. 2017) and around the world (Bruke et al. 2015; Moore and Diaz 2015). Meanwhile, policies to curb greenhouse gas emissions and address climate change can amplify existing inequalities. While the vast majority of economists support the adoption of a robust carbon tax as an efficient mechanism for reducing greenhouse gas emissions (IGM 2012), such a policy may also excessively burden the poor, depending on how carbon tax revenues are allocated. Thus, policymakers cannot confront climate change without also confronting economic inequality.

This paper considers the effect of a carbon tax on multiple forms of inequality in the United State,[3] including its effects on rich and poor households, the variation of its effect on households of similar means, and its effect on group-based inequalities. Although this paper focuses on the distributional impact of a carbon tax, we also incorporate estimates of the macroeconomic impact of different carbon tax policies to clarify tradeoff between equity and efficiency. Our analysis suggests that the US can address climate change and inequality simultaneously by returning the revenues to individuals through an equal per-capita dividend, as was recently proposed by the

[3] The U.S. does not currently have a federal carbon pricing scheme, but several states price carbon using a carbon tax or a carbon cap. As of 2016 over 40 national jurisdictions, as well as over 20 cities, states, and regions,[3] have a carbon pricing mechanism in place, and China is currently piloting what may soon be the world's largest cap-and-permit system (World Bank 2016). Relative to other high productivity economies, the U.S. is markedly behind in enacting environmental legislation that would correct this major pollution externality (Williams 2016).

Climate Leadership Council, a group of prominent Republicans and economists (Baker et al. 2017).

While economists have analyzed the distributional incidence of carbon tax policy, the literature has failed to come to a consensus on how to allocate carbon tax revenues. There are two reasons for this. First, most research on the distributional impact of a carbon tax focuses on a single form of inequality: the impact of carbon tax policies on the mean household in each income quantile. These analyses ignore other critical equity considerations, such as how policies differentially impact households within the same quantile as well as how they affect inequalities based on race and ethnicity, age, and urban-rural status. Second, the literature on the distributional impact of a carbon tax largely ignores the extensive literature on how various carbon tax policies are likely to affect the economy at large. Although research emphasizes the tradeoff between efficiency and equity, little attempt is made to bridge the insights from distributional models with those from macroeconomic models.

To address these shortcomings in the literature, this paper examines the distributional consequences of implementing a tax of $50 per ton of CO_2, which we find would redistribute up to $138 billion across U.S. households in 2020. This policy represents a substantial reorganization of property rights, and while we find the initial incidence of a carbon tax is regressive, the net distributional results hinge on how those property rights are allocated. We use Input-Output tables to estimate the carbon intensity of 64 industries and 27 expenditure categories. Using the Consumer Expenditure Survey (CEX), we then calculate the carbon footprints of a representative sample of U.S. households, which allows us to analyze multiple forms of inequality. We study three revenue-neutral carbon tax schemes: a proportional labor tax cut, an Old-Age, Survivor, and Disability Insurance (OASDI) payroll tax cut, and equal per capita dividends.

This paper's primary contribution to the literature is to provide an in-depth analysis of the effects of a carbon tax on multiple forms of inequality. The entire analysis is conducted at the household level. Like other papers, we estimate the impact of a carbon tax on the mean household in each decile. However, we also highlight the variation in welfare changes within deciles, which is ignored in most of the literature. Our household-level analysis also demonstrates how each policy affects group-based inequalities on the basis of race and ethnicity, age, and urban-rural status. Our results show that rebating carbon tax revenues in lump-sum payments not only avoids transferring income from poor households to rich households, but also minimizes redistribution among households of similar means and protects the welfare of vulnerable groups, including blacks, Hispanics, young people, senior citizens, and rural Americans.

We further contribute to the literature by incorporating macroeconomic effects of each carbon tax scheme into our distributional analysis. Bridging our findings with published estimates of the macroeconomic effects of a carbon tax provides clear evidence that the double dividend generated through a labor tax cut is insufficient to protect the purchasing power of the poor when compared to equal lump-sum rebates. Indeed, a tax-and-dividend policy is the only policy analyzed here that would benefit most individuals, including 84 percent of people in the lower class, which has received little increase in income since 1980 (Piketty 2014).

Our paper also makes several methodological refinements. Unlike other distributional analyses of a carbon tax, we include abatement costs throughout our analysis, which provides for a more complete measure of welfare changes. Additionally, the paper demonstrates the importance of using the individual as the unit of analysis to properly account for household economies of scale (Fremstad, Underwood, Zahran 2017). This is also the first analysis of a carbon tax to account for renters' CO_2 emissions when their utilities are included in their rent, which has been shown to be significant in other contexts (Glaeser and Kahn 2010; Levinson and Niemann 2004). Finally, we demonstrate the robustness of our findings by conducting the analysis with alternative carbon intensities, sorting individuals by income rather than consumption, and allowing for households' behavioral responses to vary across the income distribution.

The following section reviews the literature on the economic impact of carbon taxes schemes. Section 3 describes the data and methods utilized in this paper and presents carbon intensities for 64 industries and 27 categories of consumer goods. Section 4 presents the key results of carbon tax policies on inequality in the US. Section 5 demonstrates that our core results are similar when use an alternative method to calculate carbon intensities, sort individuals by income rather than consumption, and allow behavioral responses to differ for high- and low-income people. Section 6 discusses our results in the context of the equity-efficiency tradeoff by analyzing the potential macroeconomic effects. Section 7 concludes.

2. Background

Carbon dioxide is emitted primarily by burning fossil fuels,[4] which account for approximately 76 percent of U.S. greenhouse gas emissions (Horowitz et al. 2017).[5] While CO_2 emissions have decreased 12 percent from their peak in the United States in 2007 (Energy Information Agency 2015) they must be reduced to zero by 2100 to avoid extreme temperature change (Fawcett et al. 2015). Placing a tax on CO_2 emissions reduces demand for carbon intensive goods and services and provides incentives for individuals and firms to make investments in renewable energy and energy efficiency (Energy Information Agency 2013). Under a carbon tax, households would pay for each ton of CO_2 they directly or indirectly generate. A carbon tax that is equal to the marginal social damage of the pollution improves social welfare, therefore economists overwhelmingly support the adoption of a tax on CO_2 emissions to address climate change (IGM 2012). While a carbon tax is but one policy option to reduce emissions,[6] studies find that placing a price on emissions would be more cost-effective than other policy options, such as tightening emissions standards, subsidizing renewable energy, or investing in research and development (Fischer and Newell 2008; Williams 2016). Research also finds that a carbon tax is much less regressive than emission standards (Davis and Knittel 2016; Jacobsen 2013; Levinson 2016).

The effect of a carbon tax on inequality depends on how carbon tax revenues are distributed. Researchers have provided a range of recommendations on how to best use revenue

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[4] In 2014 major fossil fuels accounted for 5,406 metric tons of carbon dioxide emissions in the U.S., with 41 percent of emissions from burning petroleum products, 32 percent from burning coal, and 27 percent from burning natural gas (EIA 2015).

[5] The remainder of greenhouse gas emissions come from sources such as agriculture and livestock, cement production, fertilizer, and biomass burning (Pachauri et al. 2015).

[6] Our analysis can also be interpreted as the distributional consequences of increasing the price of carbon through a cap-and-trade scheme in which permits sell for $\$50/tCO_2$.

from a carbon tax, but the distributional literature focuses on devoting carbon tax revenue to three purposes: cutting taxes on capital income, cutting taxes on labor income, and rebating revenues in equal carbon dividends. However, there is little agreement on which revenue recycling scheme best balances the potential tradeoff between equity and efficiency. We see two reasons for this. First, most household-level analyses of a carbon tax address how policies redistribute income between income quantiles, ignoring other important aspects of equality. Second, most studies address either the distributional impact or the macroeconomic impact of carbon tax policies, without bridging the key results.

A large literature addresses the distributional incidence of a carbon tax. This research generally combines data on the carbon intensity of goods and services with expenditure data from the Consumer Expenditure Survey (CEX) to estimate the carbon footprints of U.S. households. Carbon intensities are calculated from Input-Output (I-O) models under the assumption that producers will fully pass price increases onto consumers. Analyses built on I-O models find that a carbon tax is regressive, since poorer households spend a greater share of income on carbon-intensive goods like electricity and gasoline (Grainger and Kolstad 2010; Hassett, Mathur, and Metcalf 2009; Mathur and Morris 2014; Metcalf 1999; Metcalf 2009). These studies also agree that using carbon tax revenues to cut taxes on capital or labor makes the policy even more regressive, while rebating carbon tax revenues in equal per capita dividends makes the policy progressive (Boyce and Riddle 2007; Boyce and Riddle 2011; Dinan 2000; Metcalf 2009).

A shortcoming of this literature is its narrow focus on how carbon tax policies transfer income between income quantiles rather than a broader analysis of its impact on inequality. The key advantage of using carbon intensities calculated from I-O models is that doing so allows for detailed, household-level impacts of carbon tax policies. However, studies concentrate on the mean incidence by income quantile (Dinan 2000; Grainger and Kolstad 2010; Hassett, Mathur, and Metcalf 2009; Mathur and Morris 2014; Metcalf 1999; Metcalf 2009) and largely ignore the variation in incidence among households of similar means. Although some papers address variation in how a carbon tax affects different regions in the U.S. (Mathur and Morris 2014; Hasset, Mathur, and Metcalf 2009; Metcalf 2009), few papers explore effects on group-based inequalities, across race and ethnicity, age group, or urban/rural status. A broader study of a carbon tax's impact on equity can clarify our options.

Another drawback of distributional studies of carbon taxes is that they generally abstract from the macroeconomic impacts of alternative carbon tax schemes. The literature emphasizes a tradeoff between equity and efficiency, but it sheds little light on how much inequality we should accept. Although the I-O models underlying these studies are not well-suited to estimating economy-wide effects, there are many general equilibrium analyses that find significant macroeconomic costs to devoting carbon tax revenues to lump-sum payments instead of reducing distortionary taxes. Research finds that the welfare of the mean household is maximized when carbon tax revenues are devoted to cutting distortionary taxes instead of funding lump-sum rebates (Goulder and Hafstead 2013; Jorgenson et al. 2015; Williams et al. 2014). Compared to cutting taxes on capital, Jorgenson et al. (2015) conclude that funding a carbon dividend reduces full consumption by about 0.3 percent, Goulder and Hafstead (2013) find that it reduces GDP by 0.3 percent, and Williams et. al (2014) find that it reduces mean welfare by 0.45 percent.

To be sure, some studies account for both their macroeconomic and distributional impacts or carbon tax policies. DeCanio's (2007) simple general equilibrium model finds that the distribution of emission allowances matters so much more than the policy's macroeconomic effects that "virtually any allocation of emissions allowances that moves in a more egalitarian direction will improve material wellbeing of a majority of the agents". The model by Williams et al. (2014), which generates a significant double dividend, finds that the middle quintile is better off under lump-sum rebates than capital or labor tax cuts. Nevertheless, the paper presents labor tax cuts as a reasonable intermediate option between capital tax cuts and equal dividends along the trade-off between efficiency and equity. Finally, Rausch, Metcalf, and Reilly (2011) combines a CGE model with CEX data to account for both macroeconomic and distributional effects of carbon tax policies. The authors describe the carbon tax incidence between income quantiles, within income quantiles, and across race and ethnicity. Although Rausch, Metcalf, and Reilly's (2011) methods are similar to those employed in this paper, it does not address which carbon tax policy best balances equity and efficiency.

3. Data and Methods

Our detailed analysis of the distributional consequences of a carbon tax is built on data on households' carbon footprints in the U.S. Calculating carbon footprints requires information on household expenditures on both direct energy goods, such as gasoline, and indirect energy goods, such as food. Consuming gasoline clearly generates CO_2 emissions, but so does consuming food, which must be planted, fertilized, harvested, and transported. We estimate carbon footprints for U.S. households from 2012 to 2014 in three steps. First, we calculate CO_2 intensities for 64 industries using the Energy Information Agency's (EIA's) CO_2 emissions data and the Bureau of Economic Analysis' (BEA's) Input-Output (I-O) tables. Second, we use these industry-level CO_2 intensities to estimate the CO_2 intensity of 27 categories of commodities defined by the Bureau of Labor Statistics (BLS). Third, we calculate the carbon footprints of a nationally-representative sample of U.S. households using spending data in the Consumer Expenditure Survey (CEX). After making the case for using the individual, rather than the household, as our unit of analysis, we address the short run distributional impact of a tax of $50 per ton of CO_2 in 2020.

During President Obama's administration, the United States Environmental Protection Agency (EPA) and other federal agencies used the social cost of carbon to estimate the climate benefits of rulemaking Table 1 presents these historical estimates of the social cost of carbon. This paper models a carbon tax of $50 per ton of CO_2, which is equal to the EPA's former estimate of the social cost of carbon for 2020 using a 3 percent average discount rate in 2017 dollars. A tax of that magnitude would increase gasoline prices by about $0.50 tax per gallon.[7]

We assume that the tax on carbon would be levied on fossil fuel producers and importers, but that price increases would ripple throughout the economy.[8] In short, coal would be taxed at the mine mouth, natural gas would be taxed at the wellhead, and oil would be taxed at the refinery (see Metcalf and Weisbach 2009). This upstream tax minimizes the number of points where the tax would need to be collected. The Congressional Budget Office estimates that there would be

[7] A rule of thumb is that $1 per ton of CO_2 is equivalent to roughly $0.01 per gallon of gasoline. This paper's central CO_2 intensity estimates suggest that a tax of $50/t$CO_2$ would have raised gas prices by $0.56 per gallon in 2013.
[8] Where the tax is levied has little to no effect on the economic or environmental implications, so the choice should be made to minimize compliance costs and maximize coverage.

Table 1: Estimates of the Social Cost of Carbon (SC-CO_2)				
	Discount Rate			
Year	5% Average	3% Average	2.5% Average	High Impact, 95th percentile at 3%
2015	\$11	\$36	\$56	\$105
2020	\$12	\$42	\$62	\$123
2025	\$14	\$46	\$68	\$138
2030	\$16	\$50	\$73	\$152
2035	\$18	\$55	\$78	\$168
2040	\$21	\$60	\$84	\$183
2045	\$23	\$64	\$89	\$197
2050	\$26	\$69	\$95	\$212

Notes. Values are in 2007 constant USD from EPA (2016). In 2020 using a 3% discount rate, the SC-CO2 is \$42 in 2007 USD or \$50 in 2017 USD.

about 2,000 collection points in the United States, (Congressional Budget Office 2001), and Metcalf and Weisbach (2009) estimate the number could be as low as 1,150.[9] Although the carbon tax would be levied on fossil fuel producers and importers, we assume the full burden of the tax would be paid by consumers in the form of price increases proportional to the carbon intensity of goods. These I-O models abstract from other channels by which a carbon tax could affect the income distribution (Fullerton 2011), but their results are consistent with some competitive general equilibrium models as well as empirical studies (Fabra and Reguant 2014).

This paper highlights the immediate distributional effects of a carbon tax. Since we use I-O tables to model the carbon tax, our analysis is constrained to the short run. As in other research (Perese 2010), our I-O model does not allow firms to change their technologies or mix of inputs.

[9] According to Metcalf and Weisbach, this would only reach about 80% of U.S. CO_{2e} emissions economy-wide. While some of the remaining emissions, such as those stemming from Chlorofluorocarbons could be taxed easily, taxing the rest (roughly 18 percent) is substantially more difficult.

Drawing from the literature, we make reasonable assumption about how households would adjust their consumption patterns in response to changes in relative prices. Like other papers (Riddle 2012), we find that our distributional results are robust to alternative assumptions regarding behavioral responses to a carbon tax.

3.1. Calculating CO_2 intensities for BEA industries

Input-Output tables from the U.S. Bureau of Economic Analysis (BEA) trace the production and use of commodities by industry. The Make matrix (M_{IxC}) lists the value of the commodities produced by each industry, and the Use matrix (U_{CxI}) lists the value of each commodity used by each industry. The BEA's annual Summary I-O tables describe the connections between 71 industries, while the most recent decennial Detailed I-O tables describe the connections between 389 industries. We begin our analysis using the Detailed Tables from 2007, which we use to inform our analysis of the more recent Summary Tables. We collapse the 389 industries and commodities in the Detailed Tables to 64 industries and commodities. Our model uses the same categories from the annual Summary Tables, with two exceptions. First, we keep electric utilities, natural gas utilities, and water and sewage utilities separate rather than collapse them into a single utilities industry; we similarly separate coal mining from all other mining industries. This allows us to calculate CO_2 intensities for goods with greater precision. Second, following Mathur and Morris (2014), we collapse the seven distinct transportation industries into a single transportation industry and the five federal, state, and local government industries into a single government industry. Doing so simplifies our analysis when we convert carbon intensities for BEA categories, which are in producer prices, into carbon intensities for Consumer Expenditure Survey categories, which are in consumer prices and account for aggregate transportation costs.

Next, we divide each column of the Make matrix by total commodity output. This Adjusted Make matrix states the share of each commodity produced by each industry. Multiplying the adjusted Make matrix by the Use matrix generates the Transactions matrix (T), which traces transactions between all 64 industries, with T_{ij} stating the value of output from industry *i* that serves as an input to industry *j*. We use the Detailed Transaction matrix for 2007 to break up utilities and mining industries in the Annual Summary Transactions matrices for 2012 to 2014. Using each Transactions matrix, we derive a Direct Requirements matrix for 64 industries (DR) by dividing the input of each industry by its Total Industry Output. DR_{ij} shows the input directly purchased from industry *i* to produce one dollar of industry *j*'s output. As demonstrated by Wassily Leontief (1986), the Total Requirements matrix (TR) is the inverse of the difference between an identity matrix and the Direct Requirements matrix, or $TR = (I\text{-}DR)^{-1}$. TR_{ij} states the input directly and indirectly required from industry *i* to produce one dollar of industry *j*.

We can now calculate carbon intensities for each of the 64 industries in our model using data on CO_2 emissions by fossil fuel type (EIA 2015; EIA 2016). The EIA provides data on the amount of CO_2 generated by burning coal, oil, and natural gas. We attribute the emissions from oil and gas to the oil and gas extraction industry and the emissions from coal to the coal mining industry. To do so, we first divide the total CO_2 attributed to each industry by its Total Intermediate Output to account for significant net imports by the oil and gas extraction industry. These direct intensities, measured in $kgCO_2/\$$, state how much CO_2 is embodied in each dollar of intermediate output of the oil and gas extraction industry (D_o) and the coal mining industry (D_c). Then, using the Total Requirements table, we calculate the intensity of all 64 industries by summing up the CO_2 emissions attributed to their direct and indirect reliance on these two industries. Specifically, the CO_2 intensity of industry *j* is given by:

$$I_j = TR_{oj} * D_{oj} + TR_{cj} * D_c \qquad \text{(Equation 1)}$$

These intensities provide an estimate of the amount of CO_2 directly and indirectly generated per dollar of output for each industry. Our estimates of CO_2 intensities for all 64 industries are presented in the Appendix Table A1. The carbon intensities vary significantly across industries. The motion picture and sound recording industry generates about 0.04kg of CO_2 per dollar of output, while the coal mining industry generates 64kg of CO_2 per dollar in 2014. These 2012-2014 intensities provide the basis for our estimates of household carbon footprints.

3.2. Calculating CO_2 intensities for BLS consumption categories

Next, we translate the CO_2 intensities of our 64 industries into the CO_2 intensities of 27 consumer expenditure categories. The Personal Consumption Expenditure (PCE) categories from the National Income and Product Accounts (NIPA), published by the BEA, do not perfectly match with the consumption categories in the Consumer Expenditure Survey (CEX) published by the BLS. We map each of our 27 CEX categories onto one or more NIPA categories using definitions from Mathur and Morris (2014). This allows us to use the PCE bridge matrix, published by the BEA, to convert producers' prices to purchaser's prices. The CO_2 intensity of each CEX category is, therefore, a weighted average of the CO_2 intensity of its producer industries, the transportation industry, the wholesale industry, and the retail industry.

Table A2 in the Appendix lists carbon intensities by CEX category. The first column presents our main estimates, described in the text above. There is less variation in the intensities listed in Table A2 than the industry-level intensities in Table 2, because the CEX intensities are weighted averages of the industry intensities, and because consumers do not purchase output directly from industries with the highest intensities. Intensities range across consumer categories, with expenditures of Tenant-Occupied Dwellings generating the lowest intensity (0.05kg of CO_2 per dollar), while expenditures on gasoline generate the highest (3.22kg of CO_2 per dollar).

We compare our intensity estimates to the implied intensities in Metcalf (1999), Mathur and Morris (2014), Horowitz et al. (2016), as well as our alternative "utility method" intensities, which we describe in Section 5.1. A direct comparison is difficult, because papers calculate CO_2 intensities for different years and somewhat different categories of consumer expenditures. Across these 27 categories, the weighted correlation between our baseline intensities and those of the other three studies is 0.92, 0.72, and 0.96, respectively. Differences in intensities may account for some of the variation in the distributional results across papers. Our method generates lower carbon intensities for both electricity and natural gas expenditures than other studies, but Section 5.1 shows that our key results also hold when we use our alternative method, which generates higher intensities for these categories.

3.3. Calculating CO_2 footprints of U.S. households

We are now able to calculate the CO_2 footprints of U.S. households by combining our estimates of carbon intensities from Table A2 with CEX data on household consumption patterns. The CEX Public Use Microdata provides detailed information on buying habits of households. We use data from the Interview Survey, which describes approximately 85-95 percent of household expenditures (CEX 2014, 33). While this survey misses household expenditures on housekeeping supplies, personal care products, and nonprescription medication, these goods are responsible for a negligible share of CO_2 emissions.

One challenge for our analysis is that 29 percent of renters (and 11 percent of all households) have some form of residential energy included in their rent. In a competitive rental market, landlords would pass the carbon tax on to these households in the form of higher rent (Glaeser and Kahn 2010; Levinson and Niemann 2004). We address this problem by imputing electricity and natural gas expenditures for households that report their landlords pay for electricity, gas, or heat using data from renters who directly pay for all utilities. We use predictive mean matching to estimate what renters indirectly pay for utilities using total household expenditures, household size, and region-quarter effects to account for seasonal variation. This imputation increases total expenditures on natural gas by about 6 percent and expenditures on electricity by about 3 percent.

Next, we construct a nationally-representative pooled cross-section of American households from 2012 to 2014. Our analysis begins with carbon footprints for 76,484 household-quarters, but after dropping 1 percent of observations with incomplete geocodes, renter information, negative total expenditures, or negative incomes we have 75,778 observations. Following other studies (Boyce and Riddle 2011; Mathur and Morris 2014), we further restrict the sample to those households that we observe for all four quarters and collapse the quarterly data to annual data, which leaves us with 9,617 household-years. Although this reduces our sample by about half, it ensures that our results are not biased by seasonal variation in carbon emissions. We uniformly increase the household survey weights so that our adjusted individual weights equal U.S. population in 2013. Each household's carbon footprint is simply the sum of the carbon embodied in each of these categories of goods:

$$\text{Carbon Footprint}_{\text{it}} = \sum_{i=1}^{27} \text{CEX intensities}_{\text{it}} * \text{CEX expenditures}_{\text{it}} \qquad \text{(Equation 2)}$$

where *it* specifies the category-year intensity.

Our sample suggests that U.S. household consumption accounts for 3.1 gigatons of CO_2 emissions per year, or 58 percent of annual emissions that enter the model in Section 3.1. It is important to recall that our method does not capture CO_2 emissions generated by federal, state, and local governments, which our industry-level intensities suggest are is responsible for 24 percent of CO_2 emissions. Accounting for government emissions, our methodology attributes 82 percent of CO_2 emissions in the U.S. to final users.

3.4. CO_2 footprints across households and individuals

The household-level incidence of a carbon tax is found by multiplying the household carbon footprints by the proposed carbon tax. Evaluating the distributional impacts of a carbon tax requires that we make several assumptions in ranking households from rich to poor. Although some studies sort households by income, the tax incidence literature has shown that annual income is volatile and may not be the best measure of household well-being (Porterba 1989). Friedman's (1957) permanent income hypothesis suggests that contemporaneous consumption is a better measure of affluence than income, which varies more over the life cycle. Thus, following Boyce and Riddle (2007), Hassett et al. (2007), and Mathur and Morris (2014), we sort the population by consumption rather than income.[10]

This study uses the individual rather than the household as the unit of analysis to properly account for variation in household size. Table 2 presents the distribution of CO_2 emissions across both households (in the left panel) and individuals (in the right panel). In the left panel, households are sorted into deciles using annual household expenditures as the measure of socioeconomic status. When sorted in this way, we observe that household size, annual household CO_2 emissions, and annual per capita CO_2 emissions rise consistently with total expenditures, but that average household size of the "richest" households is also over twice that of the "poorest" households. Using the household as the unit of analysis, only 51 percent of households emit less CO_2 per capita than the mean CO_2 emissions per capita, but many of the households with large carbon footprints have more household members than households with small carbon footprints. Using the household, rather than the individual, as the unit of analysis hides the fact that per capita emissions consistently decline with household size (Underwood and Zahran 2015; Fremstad, Underwood, and Zahran 2016).

We bypass these complications by analyzing the distribution of emissions across individuals rather than households. The right-hand panel in Table 2 sorts individuals into deciles by equivalent household expenditures, so that each decile has the same number of people. We use the common square root scale to compare consumption across households of different sizes. When individuals are sorted in this fashion, we observe greater variation in per capita CO_2 emissions

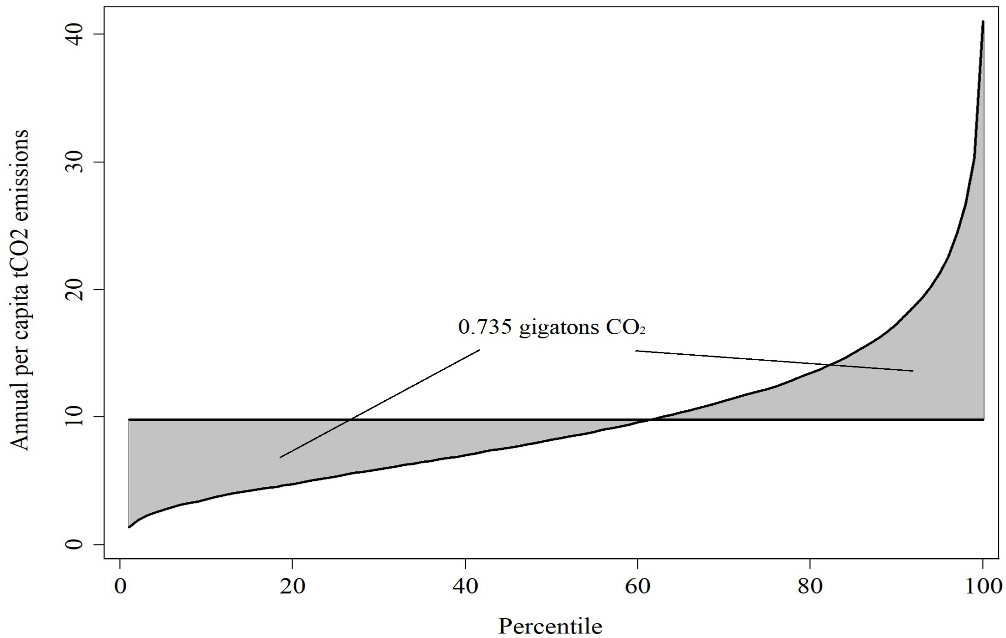
[10] Section 5.2 shows that our key results are similar when we use income rather than consumption to sort households.

Table 2: Distribution of CO2 Emissions Across Households and Individuals

Households					Individuals				
Decile by Total Household Expenditures	Household Size	Annual Household CO2 Emissions (tons/year)	Annual Per Capita CO2 Emissions (tons/year)	Fraction of Households Below Mean Per Capita CO2 Emissions	Decile by Equivalent Household Expenditures	Household Size	Annual Household CO2 Emissions (tons/year)	Annual Per Capita CO2 Emissions (tons/year)	Fraction of Individuals Below Mean Per Capita CO2 Emissions
1	1.4	7.6	6.1	0.86	1.00	3.7	11.7	3.8	0.99
2	1.8	11.6	7.8	0.71	2.00	3.6	16.3	5.3	0.95
3	2.1	14.6	9.0	0.63	3.00	3.5	18.8	6.2	0.90
4	2.3	17.5	9.6	0.59	4.00	3.4	21.9	7.3	0.84
5	2.6	19.5	10.0	0.56	5.00	3.3	23.6	8.2	0.74
6	2.7	23.3	11.1	0.50	6.00	3.4	28.0	9.5	0.61
7	2.8	26.9	12.0	0.45	7.00	4.1	32.9	10.2	0.51
8	2.9	31.4	13.5	0.36	8.00	3.2	34.2	12.1	0.34
9	3.1	37.7	14.6	0.29	9.00	3.1	39.9	14.5	0.17
10	3.3	53.5	19.8	0.11	10.00	2.9	52.6	20.7	0.05
Mean Total Population	**2.5**	**24.4**	**11.3**	**0.51**	**Mean**	**3.4**	**28.0**	**9.8**	**0.61**
Ratio of Top and Bottom Deciles	**2.3**	**7.1**	**3.3**		**Ratio of Top and Bottom Deciles**	**0.8**	**4.5**	**5.5**	

Notes. This table compares the distribution of CO_2 emissions using both households and individuals as the units of analyses. Households are sorted into deciles by household expenditures. Individuals are sorted into deciles by equivalent household expenditures using the square root scale (equivalent household expenditures = household expenditures/(household size)^1/2).

Figure 1: Distribution of Annual Per Capita CO_2 Emissions, 2012-2014



between deciles: the bottom row of Table 2 we see that people in the top decile pollute 5.5 times more than people in the bottom decile. The far-right column also indicates that 61 percent of individuals emit less than the mean CO_2 per capita. Moreover, we find that 99 percent of individuals in the poorest decile emit less than the mean but that just 5 percent of individuals in the wealthiest decile pollute less than the mean.

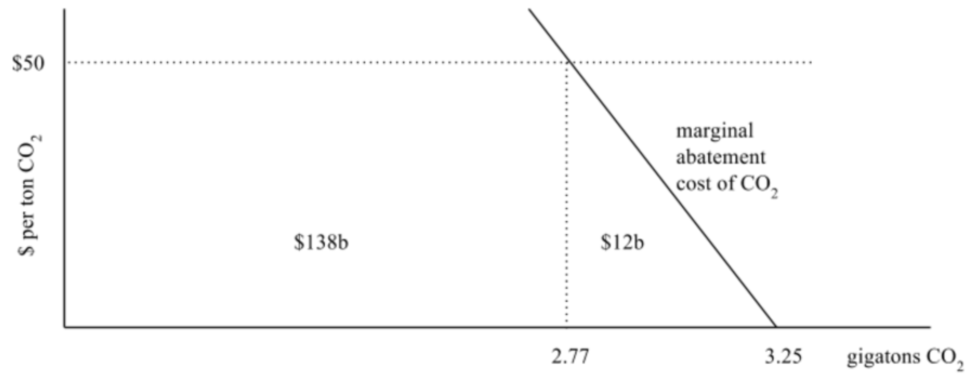
Figure 1 illustrates the distribution of emissions when individuals are sorted from lowest per capita CO_2 emissions to highest per capita CO_2 emissions. The horizontal line represents mean annual emissions per capita of 9.8 tCO_2. The figure indicates that 61 percent of individuals emit less than the mean CO_2 per capita, and that the top 1 percent of individuals emit about 4 times as much as the mean. Collectively, individuals with below-average emissions emit 0.7 gigatons less (and individuals with above-average emissions emit 0.7 gigatons more) than would be the case if everyone emitted the same amount of CO_2. If a carbon tax of $50 per ton CO_2 were devoted to dividend payments, the policy would transfer roughly $37 billion from individuals with footprints above the mean to individuals with footprints below the mean.

3.5. Behavioral response

We use our analysis of household carbon footprints in 2012-2014 to analyze the short-run distributional impact of a carbon tax $50 per tCO_2 in 2020. Without a carbon tax, we assume household carbon footprints would remain unchanged but that U.S. CO_2 emissions would increase with population through 2020 (Colby and Ortman 2015). Our model does not predict how households and firms will respond to an increase in the price of carbon-intensive goods, so we rely the economic literature to inform how the economy is likely to adjust to a tax of $50 per tCO_2. In the short run, it is reasonable to expect a tax of $50/$tCO_2$ to decrease total emissions by 15 percent (Jorgenson et al 2015, Yuan et al. 2017). The central analysis in this paper assumes that all households uniformly reduce their emissions by the same percent as they shift along linear marginal abatement cost curves.

Our behavioral assumptions are illustrated in Figure 2. Without a carbon tax, we anticipate that U.S. household expenditures will generate 3.25 gigatons of CO_2 in 2020; with a tax of $50 per ton CO_2, we assume these emissions would decrease to 2.77 gigatons in the short-run. The carbon tax would, therefore, impose $12 billion in abatement costs on U.S. households as they adjust their consumption bundles in response to changes in relative prices. At this tax rate, we expect the government to raise $138 billion annually from households in carbon tax revenues, which can be devoted to either labor tax cuts or carbon dividends. Under each revenue-neutral policy, we

Figure 2: Behavioral Response to Tax of $50/tCO$_2$e



Notes: This analysis assumes that the tax burden and abatement cost are distributed across households in proportion to their carbon footprints.

calculate each household's carbon tax burden, abatement cost, and tax cut or dividend. Our results present mean welfare gains or losses for each decile or demographic group as a percent of household expenditures.

Our analysis fails to capture some welfare gains from a carbon tax. Although the case for climate policy is frequently made on the grounds of intergenerational equity, intragenerational equity is also critical. Implementing a price on CO_2 emissions will have the added benefit of reducing co-pollutants, such as particulate matter, sulfur dioxide, NOx, and air toxins released during the burning of fossil fuels. The benefits from reducing co-pollutants, known as co-benefits, are sizable. A meta-analysis of air quality co-benefits around the world found a mean co-benefit of $56 per ton of CO_2 (Nemet et al. 2010) in addition to the Social Cost of Carbon. Our estimates of welfare gains should, therefore, be viewed as a lower-bound for each policy.

4. Distributional results

While most analyses of the distributional impact of carbon tax policies focus on how those policies shift income up and down the income distribution, our household-level data also allows for a deeper analysis of policies' impact on inequality by examining welfare changes within income deciles as well as across other group identities, including race and ethnicity, age, and urban/rural status. Tables 3, 4, and 5 present our analysis of the short-run distributional implications of a $50 tax per ton of CO_2 emissions under three revenue recycling schemes in 2020. As shown in Table 3, prior to the redistribution of revenues, price increases and abatement costs reduce welfare of the mean individual in the bottom decile by 2.8 percent, while it will reduce the mean individual in the top decile by 1.8 percent.[11] Like Mathur and Morris (2014) we find that, on average, the poorest decile pays about 50 percent more than the richest decile as a fraction of consumption.

Table 3 also reports how each of three carbon tax policies – a proportional decrease in labor taxes, a payroll tax cut, and equal carbon dividends – impacts the welfare of the mean individual in each decile as well as the fraction of individuals it benefits. Carbon tax revenues could be used to finance a proportional reduction in labor taxes. We assume the full benefit from labor tax cuts accrues to employees, and we find a carbon tax of $50 per ton of CO_2 increases workers' after-tax wages by 1.8 percent. A proportional reduction in labor taxes effectively redistributes resources from low-income individuals to high-income individuals. The bottom half of the distribution would see a mean welfare decrease of 0.57 percent while the richest decile would receive a welfare increase of 0.31 percent. However, the mean gain or loss in each decile only tells part of the story;

[11] Note that the regressivity of the tax would be greater if calculated as a percentage of income instead of expenditures. These differences are analyzed in the Section 4.2.

the distribution within deciles matters too. On the right panel of Table 3 we show the fraction of individuals better off within each decile under the three policies. The mean individual in the poorest decile receives a welfare loss of 1.56 percent under a labor tax cut, but 9 percent of individuals in this decile experiences an improvement in welfare. A labor tax cut has very different impacts within groups with similar means, because employment varies substantially within deciles. For example, while the mean person in the seventh decile benefits from the policy, 49 percent of individuals in that decile are worse off under a labor tax cut. Devoting carbon tax revenues to a labor tax cut is not just regressive, it also reduces the welfare of most Americans. As reported in the bottom rows of Table 3, coupling a carbon tax with a proportional reduction of labor taxes provides net benefits to just 40 percent of all individuals and just 30 percent of people in the bottom half of the distribution.

A payroll tax would reduce taxes on labor income without redistributing a large share to top income earners, because OASDI payroll taxes are not levied on all earned income.[12] Carbon tax revenue would be sufficient to reduce the payroll tax rate by 2.2 percentage points. Table 3 indicates that this tax swap is still quite regressive, reducing the welfare of the mean individual in the poorest decile by 1.45 percent, while having no effect on the welfare of the mean individual in the wealthiest decile. In the middle of the distribution, we see that the payroll tax cut leads to larger increases in welfare for the mean individual than the proportional labor tax cut. The policy benefits more people in the seventh, eighth, and ninth deciles than it does in the richest decile. Nevertheless, people at the bottom of the distribution continue to bear the burden of the carbon tax under an

[12] In 2013 the tax code exempted income above $113,700.

Table 3: Distribution of Burden of \$50/Ton Tax on CO_2 with Revenue Recycling								
		Welfare Gain/Loss as Percent of Household Expenditures				Fraction of Individuals Better Off		
Decile by Equivalent Household Expenditures	Equivalent Household Expenditures	No Revenue Recycling	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend
1	\$10,524	-2.80	-1.56	-1.45	5.06	0.09	0.13	0.98
2	\$15,469	-2.65	-0.98	-0.84	2.63	0.22	0.25	0.93
3	\$19,111	-2.52	-0.52	-0.36	1.71	0.35	0.39	0.86
4	\$22,739	-2.49	-0.36	-0.20	1.00	0.38	0.43	0.78
5	\$26,706	-2.31	-0.13	0.02	0.62	0.44	0.48	0.67
6	\$31,014	-2.35	-0.29	-0.14	0.18	0.40	0.45	0.51
7	\$36,171	-2.25	0.36	0.46	0.27	0.51	0.55	0.41
8	\$42,823	-2.13	0.04	0.14	-0.37	0.53	0.57	0.26
9	\$53,552	-2.02	0.31	0.21	-0.63	0.56	0.58	0.13
10	\$84,064	-1.77	0.31	0.01	-0.91	0.56	0.51	0.02
Mean Total Population	**\$34,212**	**-2.17**	**-0.03**	**-0.03**	**0.20**	**0.40**	**0.43**	**0.55**
Mean Bottom Half of Population	**\$18,908**	**-2.51**	**-0.57**	**-0.42**	**1.77**	**0.30**	**0.34**	**0.84**

Notes. Under a \$50 tax on carbon the proportional labor tax cut would increase after-tax all wages by 1.8 percent, the OASDI payroll tax cut would reduce the payroll tax rate by 2.2 percentage points, and the annual dividend amounts to \$413 per person.

OASDI payroll tax cut. Although most individuals in the top half of the distribution see welfare gains, only 34 percent of individuals in the bottom half of the distribution benefit under the policy.

Next, we analyze welfare impacts when carbon tax revenues are rebated in equal dividends. We find that a \$50 tax per ton of CO_2 would fund a lump-sum payment of \$413 per person. A tax-and-dividend scheme is a progressive policy that redistributes income from rich deciles to poor deciles: the mean individual in the bottom decile receives a welfare gain equal to 1.77 percent of expenditures, while the mean individual in the top decile would see a welfare loss equal to 0.91 percent of expenditures. Moreover, 98 percent of those in the bottom decile and 84 percent of those in the bottom half of the distribution benefit from a tax-and-dividend policy. Table 3 also shows that rebating carbon tax revenues in equal dividends also improves outcomes of the middle deciles, by both increasing the mean welfare gain and expanding the share of people who benefit from the policy. A carbon dividend is the only policy analyzed here that improves welfare for a majority of people in the U.S., and it maintains the purchasing power of over twice as many people in the bottom half of the distribution as either tax cut.

The results in Table 3 show that devoting carbon tax revenues to labor tax cuts redistributes income from the poor to the rich, and reduces the welfare of most Americans. However, a complete analysis of the impact of carbon tax policies on equality should also address how policies redistribute income across households of similar means (Cronin et al. 2017, Pizer and Sexton 2017). Studies that analyze the impact of a carbon tax on the mean person in each decile overlook the significant redistribution from non-workers to workers when carbon tax revenues are used to fund labor tax cuts. Table 4 presents the standard deviation in welfare changes as a percent of expenditures both *between* and *within* deciles under each policy. The variation in welfare changes between deciles from Table 4 shows that the dividend is the most redistributive policy. However, here it is also important to recall the direction of redistribution: a carbon dividend is the only policy analyzed here that redistributes income from the rich to the poor, rather than the reverse. Whereas a carbon dividend primarily redistributes income between deciles, labor tax cuts primarily redistributes income within deciles. The standard deviation in welfare changes within deciles is 1.53 under the proportional labor tax cut, 1.52 under the payroll tax cut, compared to 1.17 under the dividend. The reason for this is simple: everyone pays a carbon tax, but only some people earn

Table 4: Redistribution between and within Deciles		
	Standard Deviation in Welfare Changes (in percent)	
	Between deciles	Within deciles
Proportional labor tax cut	0.62	1.53
OASDI payroll tax cut	0.56	1.52
Dividend	1.80	1.17

Notes. This table presents changes in welfare as a percent of household expenditures using the individual as the unit of analysis.

labor income. Devoting revenues to some combination of labor tax cuts and benefit increases could mitigate this horizontal redistribution, but 27 percent of Americans would neither benefit from a payroll tax cut nor expanded social security benefits (Cronin et al. 2017).

A complete analysis of the impact of a carbon tax on inequality must also consider how it affects group-based inequalities. Table 5 presents our distributional findings across demographic groups. The first panel assesses the impact across race and ethnicity. The incidence of the carbon tax falls disproportionately on blacks and Hispanics. These groups would experience large welfare losses under either tax cut, with less than 40 percent of these individuals made better off. However, a dividend would result in sizable welfare gains and protect the purchasing power of 73 percent of blacks and 91 percent of Hispanics. By comparison, the stakes are modest for whites and Asians. The mean white person bears a small net loss in welfare under all policies, and there is little variation in the fraction of whites who benefit under each policy. For Asians, we find that all three policies improve welfare for 63 to 66 percent of individuals, although the mean Asian American receives larger welfare gains under the tax cuts than the dividend. These results suggest that a tax-and-dividend scheme could play a role in mitigating long-standing racial and ethnic inequalities.

Table 5: Distribution of Burden of $50/Ton Tax on CO_2 Across Demographic Groups								
		Welfare Gain/Loss as Percent of Household Expenditures				Fraction of Individuals Better Off		
	Equivalent Household Expenditures	No Revenue Recycling	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend
Race & Ethnicity								
White	$38,125	-2.15	-0.01	-0.03	-0.10	0.42	0.45	0.45
Hispanic	$23,871	-2.35	-0.31	-0.21	1.36	0.33	0.37	0.81
Black	$24,733	-2.34	-0.33	-0.24	0.86	0.30	0.35	0.73
Asian	$38,431	-1.84	0.78	0.70	0.41	0.63	0.66	0.65
Other	$34,288	-2.16	0.03	0.04	0.18	0.45	0.50	0.58
Age								
20-29	$27,182	-2.28	-0.12	0.03	0.73	0.40	0.44	0.70
30-39	$30,596	-2.18	0.16	0.19	0.72	0.46	0.51	0.71
40-49	$35,504	-2.16	0.25	0.19	0.25	0.52	0.54	0.61
50-59	$39,078	-2.14	0.23	0.20	-0.18	0.48	0.53	0.44
60-69	$38,243	-2.17	-0.33	-0.32	-0.09	0.29	0.30	0.37
70+	$30,217	-2.19	-1.60	-1.59	-0.20	0.06	0.07	0.49
Urban/Rural								
Urban	$35,271	-2.13	0.06	0.05	0.19	0.43	0.46	0.55
Rural	$27,248	-2.57	-0.78	-0.69	0.34	0.25	0.28	0.56

Notes. The Hispanic category includes all people of all races. The "other" category includes those who identify as multi-racial, Native American, or Pacific Islanders. Urban refers to household that resides inside a Metropolitan Statistical Area as defined by the Bureau of Labor and Statistics.

The distributional impact of these three carbon tax policies also varies substantially over the life cycle. While the initial incidence of the carbon tax is borne evenly across age cohorts, it falls most heavily on young people, the cohort with the lowest average expenditures. Between 40 and 44 percent of individuals in the youngest group benefit from tax cuts, compared to 70 percent under a dividend. Roughly half of individuals in the next three age brackets are better off under either labor tax cut, but a larger fraction benefits from the dividend for every age group except people in their 50s. Unsurprisingly, the starkest divide in outcomes across policies for those aged 70 and over. While all revenue recycling scenarios lead to a mean welfare loss for this group, a dividend protects almost half of the elderly, compared to just 6 or 7 percent under either tax cut. With the exception of people at the prime of their careers, every cohort is best off when carbon revenues are rebated in equal dividends.

Finally, we investigate how carbon tax policies differentially impact individuals living in rural or urban areas. As expected, we find that a carbon tax falls disproportionately on people in rural areas, both because they have greater energy needs and because they are poorer than their urban counterparts. People living in cities are modestly better off when carbon tax revenues are returned as dividends, and people living in rural areas are much better off under the tax-and-dividend scheme. The mean rural household receives a welfare loss under both tax cut, but it receives a larger welfare gain under the dividend than the mean urban household. Moreover, a dividend would benefit twice as many rural people as either labor tax cut. Our analysis suggests that carbon dividends can prevent rural households from bearing the brunt of a carbon tax, with similar fractions of urban and rural Americans benefiting from the policy.

The results presented in Tables 3, 4, and 5 provide strong evidence that the most equitable use of carbon tax revenues is to return them in equal lump-sum payments. Like other papers in this literature, we find that a tax-and-dividend scheme is the only policy that redistributes resources from rich to poor. However, we also show that carbon dividends minimize redistribution among people of similar means, and that they benefit disadvantaged groups, including blacks, Hispanics, the elderly, and people living in rural areas. After demonstrating the robustness of these distributional results, this paper will re-evaluate them in light of the equity-efficiency tradeoff.

5. Robustness

Given the complexity of calculating the incidence of a carbon tax across the income distribution, we consider the robustness of our results under alternative sets of assumptions. To ensure that our methods are not driving our results we: (1) examine the distributional results using an alternative measure of carbon intensities; (2) calculate the distributional results as a function of income rather than consumption, and (3) allow for heterogeneous behavioral responses to a carbon tax. We find that alternative carbon intensities do not significantly change our results. Likewise, our distributional results are qualitatively similar when we use income as our measure of household welfare and when we assume that poor or rich households have different marginal abatement costs.

5.1. Alternative Carbon Intensities

One reason for the wide range in distributional findings across the literature could be that papers derive substantially different carbon intensities. While our primary analysis attributes emissions from oil and natural gas to the oil and gas extraction industry and attributes emissions from coal to the coal mining industry, we use a separate method here that attributes CO_2 emissions farther down the production chain to the electricity utilities, gas utilities, and petroleum and coal products industries. We refer to this second method for calculating carbon intensities the "utility method."

The utility method assigns all the carbon emissions from coal and approximately 30 percent of emissions from natural gas to the electricity utilities,[13] the remaining 70 percent of emissions

[13] The share of natural gas used by electrical utilities ranged from 26.6% to 35.7% between 2005 and 2014 according to EIA (2016). In calculating annual intensities, we attribute the portion of natural gas used by electric utilities reported in that year.

from natural gas to natural gas utilities (EIA 2016), and all emissions from oil to the petroleum and coal product industry.[14] Our estimates of CO_2 intensities for all 64 industries are presented in Table A.1 using both our central method and this utility method. The utility method produces similar estimates for some key industries, including petroleum and coal products and gas utilities, and quite different estimates for others, such as electricity utilities, oil and gas extraction, and coal mining.

To check the implications of these alternative carbon intensities on our distributional results, Table 6 replicates Table 3 using the utility method intensities. Under these assumptions, the incidence of a carbon tax is even more regressive. Using our utility method, we find the initial incidence of a $50 carbon tax would amount to 4.1 percent of expenditures for the bottom half of the distribution, compared to 2.8 percent using our extraction method. These intensities also increase redistribution among people of similar means by amplifying variation in spending on electricity and natural gas across households. However, our core results still hold: a dividend would maintain or improve the welfare of the majority of individuals—54 percent—while tax cuts leave most people worse off. While labor tax cuts benefit just 25 percent or 29 percent of people in the bottom half of the distribution, a carbon dividend still protects the purchasing power of 76 percent of the lower class. Although we believe that our extraction method provides a better approximation of how a carbon tax would be shared across households, our key distributional results are robust to alternative carbon intensity estimates.

[14] Although this industry includes both petroleum and coal products, the Detailed 2007 Tables show that at least 97 percent of the output of this industry is petroleum products.

Table 6: Distribution of Burden of \$50/Ton Tax on CO_2 with Revenue Recycling, Utility Method								
		Welfare Gain/Loss as Percent of Household Expenditures				Fraction of Individuals Better Off		
Decile by Equivalent Household Expenditures	Equivalent Household Expenditures	No Revenue Recycling	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend
1	\$10,524	-4.14	-2.81	-2.69	4.31	0.05	0.07	0.89
2	\$15,469	-3.48	-1.69	-1.53	2.19	0.16	0.20	0.81
3	\$19,111	-3.09	-0.95	-0.77	1.45	0.28	0.34	0.75
4	\$22,739	-2.92	-0.64	-0.47	0.83	0.34	0.39	0.70
5	\$26,706	-2.64	-0.30	-0.13	0.51	0.41	0.45	0.63
6	\$31,014	-2.54	-0.32	-0.16	0.18	0.41	0.46	0.52
7	\$36,171	-2.47	0.32	0.44	0.23	0.54	0.58	0.45
8	\$42,823	-2.12	0.22	0.32	-0.23	0.58	0.63	0.35
9	\$53,552	-1.90	0.60	0.49	-0.41	0.63	0.67	0.20
10	\$84,064	-1.58	0.66	0.33	-0.65	0.67	0.63	0.05
Mean Total Population	**\$34,212**	**-2.32**	**-0.02**	**-0.02**	**0.23**	0.41	0.44	0.54
Mean Bottom Half of Population	**\$18,908**	**-3.11**	**-1.03**	**-0.87**	**1.49**	0.25	0.29	0.76

Notes. Under a \$50 tax on carbon the proportional labor tax cut would increase after-tax all wages by 1.9 percent, the OASDI payroll tax cut would reduce the payroll tax rate by 2.3 percentage points, and the equal per capita dividend amounts to \$444 per person.

5.2. Income as the Measure of Household Welfare

Up to this point, our analysis has used current expenditures as a proxy for lifetime income. In this section, we use after-tax income rather than consumption to sort individuals into deciles. It is well documented that consumption is more equally distributed than income, and that consumption varies less year-to-year since households may utilize savings or borrow against future income to smooth income shocks (Poterba 1989), but using income again tests the robustness of our key distributional results.

Table 7: Distribution of Burden of \$50/Ton Tax on CO_2 by Income								
		Welfare Gain/Loss to Household as Percent of Household Income				Fraction of Individuals Better Off		
Decile by Equivalent Household Expenditures	Equivalent Household Income	No Revenue Recycling	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend	Proportional Labor Tax Cut	OASDI Payroll Tax Cut	Dividend
1	\$8,063	-4.64	-3.84	-3.77	5.12	0.01	0.01	0.88
2	\$16,099	-2.79	-1.70	-1.61	2.08	0.07	0.09	0.80
3	\$22,106	-2.59	-1.42	-1.32	1.06	0.12	0.16	0.75
4	\$28,188	-2.14	-0.81	-0.69	0.65	0.22	0.28	0.68
5	\$34,907	-1.88	-0.44	-0.31	0.39	0.36	0.43	0.63
6	\$42,198	-1.75	-0.28	-0.16	0.17	0.44	0.51	0.52
7	\$51,093	-1.58	-0.07	0.05	-0.06	0.56	0.61	0.48
8	\$62,778	-1.43	0.12	0.23	-0.22	0.64	0.68	0.34
9	\$80,320	-1.24	0.33	0.38	-0.30	0.73	0.74	0.28
10	\$139,517	-0.85	0.73	0.47	-0.21	0.88	0.81	0.18
Mean Total Population	**\$48,512**	**-1.50**	**-0.02**	**-0.02**	**0.14**	**0.40**	**0.43**	**0.55**
Mean Bottom Half of Population	**\$21,871**	**-2.43**	**-1.17**	**-1.06**	**1.18**	**0.16**	**0.20**	**0.75**

Notes. Under a \$50 tax on carbon the proportional labor tax cut would increase after-tax all wages by 1.8 percent, the OASDI payroll tax cut would reduce the payroll tax rate by 2.2 percentage points, and the equal per capita dividend amounts to \$413 per person.

Table 7 replicates Table 3 above using equivalent household income rather than equivalent household consumption to sort individuals into deciles. Like before, we find that 55 percent of Americans would see increases in welfare under a tax-and-dividend scheme, because using income rather than consumption to sort individuals and quantify mean welfare changes does not impact *who* wins or loses; it simply changes where they fall in the distribution and the magnitude of welfare gains or losses. A carbon tax appears more regressive when the burden is calculated as a percent of income rather than consumption. The mean welfare loss for the poorest decile is 4.64 percent of income, compared to just 0.85 percent for the richest decile. Devoting carbon tax revenues to labor tax cuts is also regressive, reducing welfare of individuals in the bottom decile by 3.84 percent under a proportional labor tax. A dividend policy has the opposite effect, increasing welfare for the poorest decile by 5.1 percent. Moving from a labor or payroll tax cut to carbon dividends increases the fraction of the bottom half of the distribution that benefits from the policy from 0.16 or 0.20 to 0.75. Regardless of whether we use income or consumption to measure welfare, the majority of the population, and the poor in particular, are better off receiving a carbon dividend than either labor tax cut.

5.3. Allowing for Heterogeneous Behavioral Responses

In Section 3.5 we describe how we model households' response to a carbon tax. Since our model does not predict how households and firms will respond to an increase in the price of carbon-intensive goods, we rely on estimates from the literature. While we initially assume households would uniformly reduce emissions by 15 percent in response to a tax of \$50/tCO_2, this section allows the behavioral response to vary across the income distribution. Economic theory does not provide much guidance on whether low-income individuals are likely to reduce their emissions by a greater or smaller fraction than high-income individuals, but policymakers may be concerned that low-income people do not have sufficient capital or credit to achieve sizable abatement. To test the robustness of our results, we assume that the economy still reduces emissions by 15 percent, but vary how much low- and high-income households abate. First, we assume low-income deciles abate less than high-income deciles, which makes the entire carbon tax slightly more regressive, regardless of the revenue recycling mechanism. Second, we assume the opposite - that the poor have a larger behavioral response and reduce their carbon emissions by a greater fraction than the rich. In both cases, our core distributional findings hold: carbon dividends are the only policy to benefit a majority of people, especially the bottom half of the distribution. While some uncertainty remains as to how households across the income distribution will respond to a carbon tax, these findings indicate that our results are robust to either the rich or the poor having a larger behavioral response.

6. Discussion

The economic literature largely agrees that the initial incidence of a carbon tax is regressive. This study interrogates the distributional implications of a carbon tax under three revenue recycling schemes to see if carbon taxes necessarily exacerbate existing inequalities. We find that the tax-and-dividend scheme is the only policy to reduce inequality between rich and poor. We also find that a per capita dividend mitigates other forms of inequality, by dampening redistribution among households of similar means and mitigating group-based inequalities. Carbon dividends are also the only policy that improves the welfare of the majority of Americans.

While a tax-and-dividend policy is the most equitable option, it comes at some macroeconomic cost. Economic theory suggests that using carbon tax revenue to reduce distortionary taxes can yield a double dividend by both reducing CO_2 emissions and reducing the economic cost of the tax system (Goulder and Hafstead 2013). Like other analyses of the incidence of a carbon tax, we ignore the effect of each policy on the economy as a whole in our central analysis, but here we evaluate how these macroeconomic effects fit with our distributional results.

Most general equilibrium papers find that reductions in taxes on capital and corporations generate the largest positive macroeconomic effects, but the benefits to capital tax cuts flow

Table 8: Equity versus efficiency					
		Welfare Gain/Loss as Percent of Household Expenditures		Fraction of Individuals Better Off	
Decile by Equivalent Household Expenditures	Equivalent Household Expenditures	Proportional Labor Tax Cut with Macro-economic Effect	Dividend	Proportional Labor Tax Cut with Macro-economic Effect	Dividend
1	$10,524	-1.48	5.07	0.12	0.98
2	$15,469	-0.89	2.63	0.24	0.93
3	$19,111	-0.41	1.71	0.38	0.87
4	$22,739	-0.24	1.00	0.40	0.78
5	$26,706	-0.01	0.61	0.46	0.67
6	$31,014	-0.18	0.18	0.43	0.51
7	$36,171	0.50	0.27	0.54	0.41
8	$42,823	0.16	-0.37	0.56	0.26
9	$53,552	0.44	-0.63	0.58	0.13
10	$84,064	0.42	-0.91	0.58	0.02
Mean Total Population	**$34,212**	**0.09**	**0.20**	**0.43**	**0.55**
Mean Bottom Half of Population	**$18,908**	**-0.46**	**1.77**	**0.32**	**0.84**

Notes. This table presents key distributional results under the assumption that devoting carbon tax revenues to labor tax cuts increases the welfare of wage earners by 0.1 percent.

overwhelmingly to the wealthiest households (Clausing 2011; Clausing 2013; Horowitz et al. 2017). The literature finds smaller macroeconomic benefits from cutting labor taxes, concluding that these tax cuts raise welfare by about 0.1 percent relative to lump-sum payments (Goulder and Hafstead 2013; Jorgenson et al. 2015).

If these macroeconomic benefits accrue to proportionately to households' labor income, they have very little impact on our key distributional results. Table 8 incorporates these economy-wide benefits into our distributional analysis. This increases mean welfare gain of each decile by approximately 0.1 percent relative to Table 3, but this does little to help people in the bottom half of the distribution, who now experience a mean welfare loss of 0.46 percent instead of 0.57 percent.

Although carbon dividends do not produce a double dividend, they are still the only policy that protect the welfare of more people than a labor tax cut, including over twice as many people in the bottom of the distribution. Similar to DeCanio (2007), this simple analysis suggests that the distributional incidence of a carbon tax swamps any macroeconomic benefit from cutting distortionary taxes.

Finally, the central results in the paper describe the distributional effect of a modest carbon tax, but these equity considerations become even more salient at higher carbon prices. We analyzed a tax of $50 per ton of CO_2 since that is a central estimate of the social cost of carbon, but this tax may nevertheless be too low. Tol (2013) conducts a review of 588 studies based on different integrated assessment models, policy assumptions, and discount rates and finds the mean social cost of carbon is $220/t$CO_2$. Further, a carbon price of $50 per ton of CO_2 would only reduce emissions by an estimated 15 percent in the short runs. A much larger carbon tax would be necessary to reach the goal of limiting global warming to 2 degrees Celsius. To estimate the distributional impact of an aggressive carbon tax we consider a tax of $220 per ton of CO_2, which we assume would reduce greenhouse gas emissions by 40 percent in the short-run. Our model suggests that a tax of this magnitude would reduce the welfare of people in the poorest decile by over 10 percent. While a tax of $50/t$CO_2$ leads to relatively small transfers between households, a tax of $220/t$CO_2$ could redistribute over $400 billion a year. Nevertheless, our data suggests that a carbon dividend would protect the purchasing power of 42 percent of individuals through a transition away from a carbon-based economy, including 72 percent of Americans in the bottom half of the income distribution.

7. Conclusion

This paper models the short-run distributional impacts of placing a $50 tax per ton of CO_2. We combine carbon emissions data from the EIA and the economy-wide Input-Output tables from the BEA to calculate the carbon intensity of 64 industries and 27 categories of goods to estimate carbon footprints for a representative sample of U.S. households in the in the CEX. We then analyze the impact of a carbon tax on inequality in the U.S.

Our results indicate that Americans in the richest decile emit over five times as much CO_2 as Americans in the poorest decile, but that a carbon tax would nevertheless cost poor households a higher percentage of their consumption or income than the rich. We model the full impact when carbon tax revenues are used to fund a proportional reduction in all labor taxes, a payroll tax cut, and carbon dividends. While a carbon tax disproportionately burdens people at the bottom of the distribution, we find that the policy can be made progressive if the revenue is rebated to the public in equal per capita dividends. Although devoting carbon tax revenues to labor tax cuts *reduces* the welfare of 91 percent of Americans in the bottom decile, using revenues to pay for carbon dividends *increases* the welfare of 98 percent of people in the poorest decile. Neither tax cut modeled here would preserve the purchasing power of most Americans, whereas carbon dividends maintain or increase the welfare of 55 percent of Americans, including 84 percent of those in the bottom half of the income distribution. We also show that a tax-and-dividend policy minimizes redistribution among households of similar means, and mitigates longstanding inequalities by race and ethnicity and along the urban/rural divide.

This paper further demonstrates that our key results are robust to alternative carbon intensities, the use of income rather than expenditures to measure welfares, and heterogeneous behavioral responses. Finally, we incorporate findings on the macroeconomic effects of carbon tax policies to show that the double dividend is too small to significantly alter our distributional results. We own the atmosphere in common, so there is a strong moral case for paying every person an equal amount for its use. This paper demonstrates that devoting carbon tax revenues to dividends also increases the fraction of the population that will benefit from the policy, with little cost in terms of economic efficiency.

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Table A1: Comparison of Carbon Intensities (kgCO2/$) by Industry					
	From 2007 Detailed Tables		Extraction Method, Using Annual Summary Tables to Update 2007 Detailed Tables		
Industry Name	Extraction Method	Utility Method	2012	2013	2014
Farms	0.83	0.54	0.67	0.57	0.58
Forestry, fishing, and related activities	0.34	0.25	0.17	0.18	0.19
Oil and gas extraction	8.90	0.14	6.95	6.96	7.17
Support activities for mining	0.45	0.24	0.28	0.29	0.26
Construction	0.57	0.34	0.70	0.66	0.62
Food and beverage and tobacco products	0.73	0.43	0.56	0.52	0.51
Textile mills and textile product mills	0.71	0.51	0.48	0.47	0.45
Apparel and leather and allied products	0.27	0.23	0.27	0.27	0.27
Wood products	0.49	0.40	0.50	0.49	0.47
Paper products	1.36	0.65	0.80	0.77	0.74
Printing and related support activities	0.50	0.39	0.43	0.41	0.40
Petroleum and coal products	5.89	4.67	4.73	4.67	4.72
Chemical products	0.81	0.60	0.59	0.56	0.55
Plastics and rubber products	0.71	0.52	0.62	0.63	0.61
Nonmetallic mineral products	1.71	0.60	2.78	2.75	2.64
Primary metals	4.72	0.61	10.12	10.19	9.50
Fabricated metal products	1.41	0.36	2.65	2.54	2.42
Machinery	0.93	0.29	1.73	1.57	1.50
Computer and electronic products	0.35	0.17	0.45	0.39	0.38
Electrical equipment, appliances, and components	1.18	0.35	2.19	2.14	1.99
Motor vehicles, bodies and trailers, and parts	0.91	0.30	1.37	1.31	1.26
Other transportation equipment	0.52	0.20	1.03	0.96	0.98
Furniture and related products	0.61	0.31	1.01	0.95	0.93
Miscellaneous manufacturing	0.52	0.25	0.95	1.05	0.99
Wholesale trade	0.17	0.16	0.12	0.12	0.12
Motor vehicle and parts dealers	0.13	0.13	0.15	0.14	0.13
Food and beverage stores	0.22	0.32	0.15	0.15	0.15
General merchandise stores	0.20	0.25	0.13	0.13	0.13
Warehousing and storage	0.33	0.42	0.23	0.24	0.23
Other retail	0.20	0.23	0.14	0.14	0.14

Publishing industries, except internet (includes software)	0.15	0.12	0.10	0.10	0.08
Motion picture and sound recording industries	0.12	0.11	0.04	0.04	0.04
Broadcasting and telecommunications	0.13	0.11	0.18	0.16	0.16
Data processing, internet publishing, and other information services	0.20	0.17	0.25	0.26	0.27
Federal Reserve banks, credit intermediation, and related activities	0.12	0.10	0.05	0.06	0.06
Securities, commodity contracts, and investments	0.16	0.16	0.09	0.10	0.10
Insurance carriers and related activities	0.06	0.06	0.04	0.05	0.04
Funds, trusts, and other financial vehicles	0.13	0.12	0.07	0.08	0.08
Rental and leasing services and lessors of intangible assets	0.16	0.13	0.16	0.18	0.18
Legal services	0.10	0.10	0.06	0.07	0.07
Miscellaneous professional, scientific, and technical services	0.19	0.15	0.16	0.17	0.17
Computer systems design and related services	0.11	0.11	0.07	0.07	0.06
Management of companies and enterprises	0.18	0.20	0.12	0.12	0.12
Administrative and support services	0.17	0.14	0.16	0.17	0.17
Waste management and remediation services	0.43	0.27	0.58	0.55	0.53
Educational services	0.27	0.33	0.22	0.24	0.24
Ambulatory health care services	0.17	0.17	0.14	0.14	0.13
Hospitals	0.24	0.23	0.18	0.21	0.21
Nursing and residential care facilities	0.26	0.29	0.17	0.19	0.18
Social assistance	0.24	0.23	0.20	0.19	0.18
Performing arts, spectator sports, museums, and related activities	0.16	0.17	0.14	0.14	0.13
Amusements, gambling, and recreation industries	0.29	0.31	0.24	0.25	0.23
Accommodation	0.26	0.28	0.19	0.17	0.17
Food services and drinking places	0.35	0.31	0.24	0.24	0.23
Other services, except government	0.23	0.21	0.20	0.21	0.21
Housing	0.05	0.03	0.04	0.05	0.05
Other real estate	0.64	0.84	0.29	0.32	0.31
Coal mining	72.96	0.48	66.52	67.56	63.67
Electricity utilities*	2.68	8.33	1.94	2.24	2.18

Natural gas utilities	3.45	5.99	1.53	1.82	2.08
Government	0.57	0.33	0.44	0.41	0.39
All mining except coal, oil, and gas	0.91	0.63	2.18	2.13	1.97
Transportation*	1.05	0.76	1.01	1.00	0.99
Water utilities	0.32	0.31	0.24	0.26	0.26

Notes. See text for description of author's two methods for calculating carbon intensities. A (*) denotes author-generated industries in Summary Tables. Authors combine multiple industries into Government and Transportation industries. Authors use data from Detailed 2007 Tables to break up Utilities into Electrical, Gas, and Water Utilities in Summary Tables. The results in this paper use the intensities we calculate for 2012, 2013, and 2014.

Table A2: Carbon Intensities of Consumer Goods Across Authors (kgCO2/$)					
Consumer Expenditure Survey Categories	Fremstad and Paul (2017) for year 2013	Metcalf (1999) for year 1992	Mathur & Morris (2014) for year 2010	Horowitz et al. (2016) for year 2007	Fremstad and Paul (2017) for year 2013 using "utility method"
Airfare	1.00	0.48	1.34	2.18	0.61
Alcohol	0.33	0.16	0.48	0.14	0.20
All Education	0.24	0.13	0.29	0.53	0.34
Auto Insurance	0.05	0.08	0.04	0.07	0.04
Autos	0.73	0.20	0.69	0.22	0.17
Books	0.22	0.18	0.23	0.17	0.14
Charity	0.19	0.13	0.17	0.20	0.16
Clothes	0.22	0.20	0.23	0.23	0.18
Electricity	2.24	3.00	3.47	3.60	7.40
Food at Home	0.39	0.23	0.55	0.58	0.24
Food at Restaurants	0.24	0.13	0.31	0.07	0.17
Furnishings	0.71	0.20	0.49	0.34	0.22
Gasoline	3.22	2.90	3.15	5.92	2.11
Health	0.22	0.13	0.21	0.22	0.16
Home Heating Fuel	2.75	3.03	4.07	5.80	1.80
Household Supplies	0.36	0.00	0.55	0.23	0.20
Life Insurance	0.05	0.08	0.04	0.07	0.04
Mass Transit	0.94	0.20	0.50	1.84	0.58
Natural Gas	1.82	4.90	12.61	5.93	6.90
Other Car Services	0.23	0.13			0.14
Other Dwelling Rentals	0.06	0.13	0.13	0.28	0.04
Other Recreation	0.25	0.13	0.21	0.46	0.15
Recreation and Sports	0.70	0.18	0.42	0.23	0.20
Telephone	0.18	0.15	0.18	0.17	0.10
Tenant-Occupied Dwellings	0.05	0.05	0.11	0.35	0.02
Tobacco	0.36	0.10	0.43	0.14	0.22
Water	0.38	0.15	0.31	0.98	0.24

Notes. Authors calculate implied intensities using published price increases in Table A1 in Mathur and Morris (2014), Table 3 in Metcalf (1999), and Table 2 in Cronin et al. (2017). We describe how we calculate our alternative "utility method" intensities in Section 5.1.